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AGRICULTURE/FORESTRY HYDROLOGY

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Type III Final Report

Mr. Frederick Gordon
Technical Monitor
Code 902
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

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Mr. Frederick Gordon

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- Mapping programme
- Computer Compatible Tapes

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15. Abstract

Thematic maps at a scale 1:1,000,000 were prepared by interpretation of LANDSAT-1 and LANDSAT-2 imagery and from documents, maps and aerial photographs available at the Mekong Secretariat and the riparian countries.

A modified version of the RECOG model of Colorado State University was installed on an IBM 370/145. The model is considered to be a research tool for the automatic interpretation of LANDSAT imagery.

CONTENTS

1. OBJECTIVES

The main objectives of the Mekong Committee investigations using LANDSAT-2 data are as follows :

A. Short-term objectives

By both photo-interpretation and automatic data processing techniques, supported by ground truth data and field surveys, establish :

Land use, pedo-geomorphology and land capability maps of the lower Mekong basin;

Maps showing primary forests and deciduous forest areas;

Maps showing consecutive flood and drainage patterns of Mekong lowlands.

B. Long-term objectives

Organise a research programme for classification of agricultural crops and land use, and for soil moisture monitoring for crop forecasting.

2. TECHNIQUES

2.1 Data quality and delivery

For the identification of LANDSAT-2 data the test area of the lower Mekong basin is defined by a convex polygon with five corners as follows :

No.	Latitude	Longitude
1	20° 00' N	100° 00' E
2	20° 00' N	106° 00' E
3	12° 00' N	111° 00' E
4	08° 00' N	105° 00' E
5	16° 00' N	100° 00' E

Ten LANDSAT ground tracks and 55 LANDSAT scene frames cover the entire test area of about 600,000 km^2 which cover the whole Lao PDR

/ and

and Kampuchea, the north and northeast Thailand, and the Mekong delta and the highlands in Southern Viet-Nam (Map 1).

The data output received during the period of investigation is listed in Annex 1.

The quality of the imagery from LANDSAT-2 has improved very considerably in comparison with those from LANDSAT-1; moreover certain gaps in LANDSAT-1 data of cloudy areas, especially over the Annamite mountain chain are being filled now.

The delivery time (between date the picture are taken and received in Bangkok) was approximately 2 months and 20 days, which is for the purpose of our investigations quite satisfactorily.

2.2 Ground truth collection

2.2.1 An extensive coverage

An extensive ground truth coverage was conducted for the preparation of thematic maps. Ground control or verification was carried out mainly on the basis of aerial photographs and maps, made available by the national offices concerned in the four riparian countries. Though this information was often rather old (1954 to 1960), comparison with satellite data made it possible to update vegetational units in a generally precise manner. The early maps and aerial photographs were also used to prepare the maps of areas for which only poor quality images were available. The updating, in this case, lacks precision, especially for the province of Loei in Thailand and for the areas located west of the Mekong between Luang Prabang and Paklay in Lao PDR.

In some areas, the absence of any documentation and the impossibility of carrying out ground truth observations made it difficult to identify and describe vegetational formations, as in the northern part of Lao PDR and the areas located northeast of Thakhek.

Ground truth controls were also carried out in the north-eastern provinces of Thailand but they were rather limited.

/ 2.2.2

2.2.2 An intensive coverage

A more detailed ground truth coverage was conducted for the purpose of providing field informations to be used in the computer supervised classification. Two basic data collection systems for obtaining the ground truth observations during the time that LANDSAT-2 satellite passes over two selected sites for a period of one year starting from August 1975 were carried out. These test sites were the area along Phaholyothin Highway from Km. 29 just north of Don Muang Airport to Km. 65 (Wang Noi District) and the area in Tambon Bang Khan, a subdistrict of Klong Luang District, Pratumthani Province. Ground informations collected indicated crop seasonal changes, and man-made objects within the test perimeter along the Highway permited the ground check points to identify and to map against the desired satellite imagerial pixels.

Seven main features in the above mentioned sites were collected, i.e., rice, grass, bush, housing or factory, bareground, water and soil conditions. During the field observation, the environmental and atmospheric conditions at AIT Water-Resources Laboratory were recorded. Colour photographs were also taken at every Kilometer mark along the Phaholyothin Highway.

The recorded data was manually checked and key-punched onto cards and then edited by a computer programme before storing in an computer file for easy retrieval. To retrieve the information from the file, observation date and test site type were selected as the primary indices for each data set. Then each record may be retrieved using its field identification.

2.3 Preparation of thematic maps based on satellite imagery

The land use, pedo-geomorphology and land capability maps at a scale of 1:1,000,000 were prepared by interpretation of imagery from the coverages of LANDSAT-1 and LANDSAT-2 and from documents, maps, and aerial photographs already available at the Mekong Secretariat or in the various government offices of the four riparian countries.

/ The

The investigation covers the lower Mekong basin, an area of approximately 630,000 km^2 which includes :

- all of the Lao People's Democratic Republic, except for the northern extremity of the country;

- most of Democratic Kampuchea with the exception of the south-western areas draining into the Gulf of Thailand;

- the northeast provinces and the northern extreme of Thailand, as well as a small portion of the southeast;

- the Mekong delta area and part of the southern highlands (Ban Me Thuot-Pleiku-Kontum) of the Socialist Republic of Viet-Nam.

The whole lower Mekong basin was covered by 10 LANDSAT passes which 55 frames of imagery were needed. Subsequently overlapped coverages of the same area were used and the effects of seasonal changes indicated clearly different types of vegetation cover. Unfortunately, numerous frames were rendered partly or totally unusable because of cloud cover, especially during the rainy season.

The working material used corresponded to black and white positive transparencies at the scale of 1:1,000,000 in the various bands. A few photographic enlargements at a scale of 1:500,000 were also prepared (primarily for bands 5 and 7 of the LANDSAT-1 satellite) as well as numerous composite colour transparencies at a scale of 1:1,000,000 obtained by the superimposition of bands 4 (yellow), 5 (magenta), and 7 (blue) monochromatic positive transparencies at the same scale.

Band 4 images, which have poor contrast, were generally of little use by themselves. Band 5 images give better contrasts and shades for the study of the land use and the vegetation cover. Interpretation of bands 6 and 7 images gave an idea of geomorphology, soil humidity, and the hydrographic network.

The Land Use Map was first prepared on the basis of data supplied by the LANDSAT-1 satellite (1972-1973). Subsequent LANDSAT-2 imagery (1975-1976) proved of better quality and these were the

/ images

6

images primarily used to prepare the Pedo-geomorphologic Map. The Land Capability Map was prepared on the basis of the Pedo-geomorphologic Map.

As might be expected, the quality of images from an area as extensive and varied as the Mekong basin varies greatly from one area to another. Data obtained under the best conditions from some regions can hardly be extended to the entire area. Ground truth controls are required, but these have not yet been carried out. Therefore, legends given on the maps have only an average representative value as regards the whole basin.

2.4 Research programme for computer processing of remote sensing data

In conducting this study, the plan was divided in three phases as:

a) Study computer programme functions of the RECOG package of the Colorado State University and modify the model from the CDC 6400 version to be compatible to an IBM 370/145. Every machine dependent routine is to be converted to FORTRAN.

b) Reformat input tape of the LANDSAT-1 and test the RECOG programme. Re-organize its input/output routines.

c) With reference to the informations obtained from the supplemental study on ground truth observation carried out from August 1975 to August 1976, the computer interpretation of the LANDSAT-2 computer compatible tapes coincided with the ground observation will be conducted in order to determine the model's capability as well as accuracy of its classification.

3. ACCOMPLISHMENTS DURING THE PERIOD UNDER REVIEW

3.1 Preparation of land use, pedo-geomorphologic and land capability maps

The land use map at the scale of 1:1,000,000 was published

/with

with descriptive legend in English and in French. (copies were attached to the March 1977 Quarterly Report)

The preparation of sketches for the pedo-geomorphologic and land capability maps was finished. These two maps are being printed.

Also, a report entitled "Preparation of Thematic Maps on the Basis of Satellite Imagery" was published (Annex 2).

3.2 Research programme for computer processing of remote sensing data

The RECOG package of the Colorado State University was modified and installed on an IBM 370/145 computer at the Asian Institute of Technology. The model is considered to be a research tool for interpretation and classification of LANDSAT imagery data recorded on computer compatible tapes.

Ground truth observations were carried out at the two selected sites during August 1975 to August 1976. Since the LANDSAT-2 computer compatible tapes over the observation areas are unavailable, the computer classification of the test areas were not conducted. Instead, the classification was demonstrated over the areas in the vicinity of Bangkok and the Gulf of Thailand using LANDSAT-1 computer compatible tapes.

The final report on "Computer Processing of Remote Sensing Data" completed in March 1977 is attached as Annex 3.

4. CONCLUSION

Determined by their aspect, the main vegetation units of the lower Mekong basin and the land development conditions have been mapped by interpretation of LANDSAT-1 data. By interpretation of the various shades of gray observed on satellite images, it was possible to map the density of the vegetation cover. The study of their seasonal variations makes it possible to distinguish between

/ mainly

ORIGINAL PAGE IS OF POOR QUALITY

mainly deciduous forests. In the Mekong basin area, these are generally related to the density of the vegetation cover.

In view of the absence of documentation, the impossibility of carrying out ground truth control, and the often poor quality of some satellite pictures, it was impossible to give all the precision required to the map and to the descriptions of vegetation units in some areas.

A more detailed mapping would certainly required intensive as well as extensive ground truth coverages of the lower Mekong basin which were not possible during the preparation of these maps.

A modified version of the RECOG model was installed on an IBM 370/145 computer. The model is considered to be a research tool for automatic interpretation of LANDSAT imagery.

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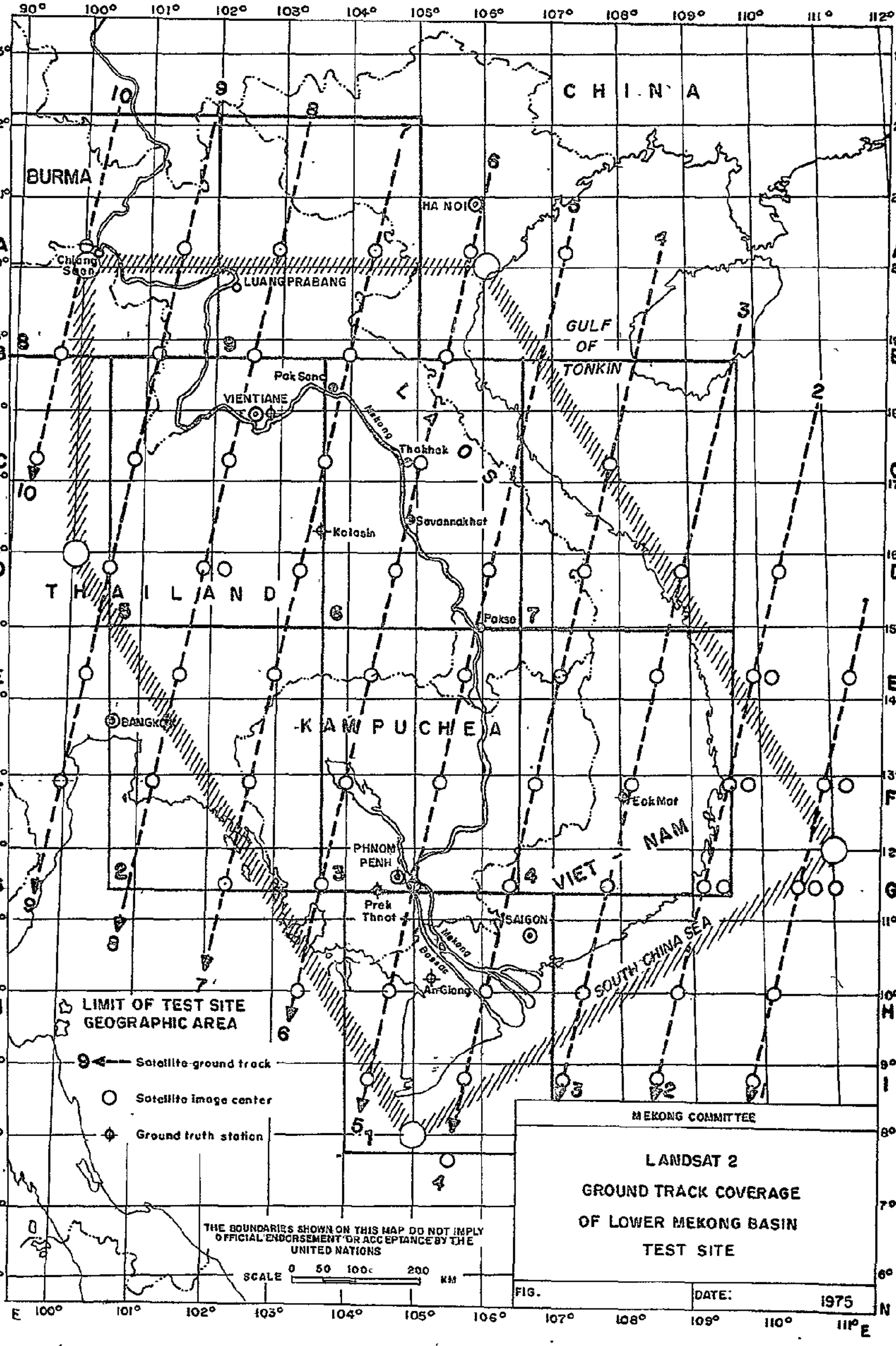
5. <u>M A P</u>

MAP I.



CHINA
BURMA
LAOS
THAILAND
KAMPUCHEA
VIET NAM
GULF OF TONKIN
SOUTH CHINA SEA
HA NOI
Chiang Saen
LUANG PRABANG
Pak Sane
VIENTIANE
Thakhek
Savannakhet
Kalasin
Pakse
BANGKOK
PHNOM PENH
Prek Thnot
SAIGON
An Giang
Eok Mat
Mekong
Bassac
LIMIT OF TEST SITE
GEOGRAPHIC AREA
Satellite ground track
Satellite image center
Ground truth station
THE BOUNDARIES SHOWN ON THIS MAP DO NOT IMPLY OFFICIAL ENDORSEMENT OR ACCEPTANCE BY THE UNITED NATIONS
SCALE 0 50 100 200 KM
MEKONG COMMITTEE
LANDSAT 2
GROUND TRACK COVERAGE
OF LOWER MEKONG BASIN
TEST SITE
FIG.
DATE: 1975

6. A N N E X E S

ANNEX 1

LIST OF LANDSAT-2 IMAGERY
RECEIVED BY THE MEKONG SECRETARIAT
(March 1975 - June 1977)

ANNEX 1

LIST OF LANDSAT-2 IMAGERY

RECEIVED BY THE MEKONG SECRETARIAT

(March 1975 — June 1977)

	ID number	Date acquired (month, day, year)		
1	2048-02152	03	11	75
2	2048-02155	03	11	75
3	2049-02204	03	12	75
4	2049-02211	03	12	75
5	2049-02213	03	12	75
6	2049-02220	03	12	75
7	2051-02312	03	14	75
8	2051-02314	03	14	75
9	2051-02323	03	14	75
10	2051-02335	03	14	75
11	2051-02341	03	14	75
12	2053-02440	03	16	75
13	2053-02442	03	16	75
14	2053-02445	03	16	75
15	2067-02205	03	30	75
16	2067-02212	03	30	75
17	2067-02214	03	30	75
18	2069-02325	04	01	75
19	2069-02331	04	01	75
20	2070-02392	04	02	75
21	2073-02534	04	05	75
22	2073-02541	04	05	75
23	2073-02543	04	05	75
24	2075-03044	04	07	75
25	2075-03051	04	07	75
26	2075-03053	04	07	75
27	2088-02360	04	20	75
28	2106-02355	05	08	75
29	2108-02472	05	10	75
30	2139-02203	06	10	75
31	2157-02203	06	28	75
32	2162-02491	07	03	75
33	2162-02494	07	03	75
34	2162-02500	07	03	75
35	2163-02543	07	04	75
36	2163-02550	07	04	75
37	2163-02552	07	04	75
38	2164-02595	07	05	75
39	2179-02414	07	20	75
40	2192-02144	08	02	75
41	2192-02151	08	02	75
42	2210-02141	08	20	75
43	2210-02143	08	20	75
44	2211-02195	08	21	75
45	2211-02201	08	21	75

	ID number	Date acquired (month, day, year)		
46	2212-02244	08	22	75
47	2248-02250	09	27	75
48	2264-02135	10	13	75
49	2290-02581	11	08	75
50	2301-02193	11	19	75
51	2301-02200	11	19	75
52	2303-02301	11	21	75
53	2303-02303	11	21	75
54	2303-02310	11	21	75
55	2304-02353	11	22	75
56	2304-02362	11	22	75
57	2304-02364	11	22	75
58	2304-02371	11	22	75
59	2304-02373	11	22	75
60	2305-02413	11	23	75
61	2305-02425	11	23	75
62	2306-02463	11	24	75
63	2306-02464	11	24	75
64	2306-02465	11	24	75
65	2306-02472	11	24	75
66	2306-02474	11	24	75
67	2306-02481	11	24	75
68	2308-02570	11	26	75
69	2303-02573	11	26	75
70	2320-02235	12	08	75
71	2320-02241	12	08	75
72	2320-02250	12	08	75
73	2320-02253	12	08	75
74	2320-02255	12	08	75
75	2321-02313	12	09	75
76	2323-02403	12	11	75
77	2323-02410	12	11	75
78	2324-02462	12	12	75
79	2324-02464	12	12	75
80	2326-02581	12	14	75
81	2340-02341	12	28	75
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83	2340-02353	12	28	75
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85	2340-02362	12	28	75
86	2341-02393	12	29	75
87	2341-02400	12	29	75
88	2341-02402	12	29	75
89	2341-02405	12	29	75
90	2341-02411	12	29	75
91	2341-02414	12	29	75
92	2342-02452	12	30	75
93	2343-02510	12	31	75
94	2343-02512	12	31	75
95	2343-02515	12	31	75

	ID number	Date acquired (month, day, year)		
96	2345-03023	01	02	76
97	2345-03025	01	02	76
98	2345-03032	01	02	76
99	2345-03034	01	02	76
100	2356-02244	01	13	76
101	2357-02294	01	14	76
102	2357-02300	01	14	76
103	2358-02343	01	15	76
104	2359-02392	01	16	76
105	2359-02395	01	16	76
106	2359-02401	01	16	76
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108	2359-02410	01	16	76
109	2359-02413	01	16	76
110	2359-02415	01	16	76
111	2359-02422	01	16	76
112	2360-02453	01	17	76
113	2360-02460	01	17	76
114	2360-02462	01	17	76
115	2360-02465	01	17	76
116	2360-02471	01	17	76
117	2360-02474	01	17	76
118	2361-02505	01	18	76
119	2361-02511	01	18	76
120	2361-02520	01	18	76
121	2361-02523	01	18	76
122	2361-02525	01	18	76
123	2362-02563	01	19	76
124	2362-02572	01	19	76
125	2362-02575	01	19	76
126	2362-02581	01	19	76
127	2363-03022	01	20	76
128	2363-04453	01	20	76
129	2373-02184	01	30	76
130	2373-02191	01	30	76
131	2374-02242	01	31	76
132	2374-02245	01	31	76
133	2374-02251	01	31	76
134	2375-02294	02	01	76
135	2375-02301	02	01	76
136	2375-02303	02	01	76
137	2375-02310	02	01	76
138	2376-02344	02	02	76
139	2376-02350	02	02	76
140	2376-02353	02	02	76
141	2377-02395	02	03	76
142	2377-02404	02	03	76
143	2377-02411	02	03	76
144	2377-02402	02	03	76
145	2378-02454	02	04	76

	ID number	Date acquired (month, day, year)
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147	2379-02510	02-05-76
148	2397-02500	02-23-76
149	2397-02503	02-23-76
150	2398-02555	02-24-76
151	2398-02561	02-24-76
152	2398-03013	02-25-76
153	2399-03015	02-25-76

ANNEX 2

REPORT ON
PREPARATION OF THEMATIC MAPS
ON THE BASIS OF SATELLITE IMAGERY

Distr. LIMITED

MKG/49
April 1977

ENGLISH

ORIGINAL : FRENCH

UNITED NATIONS

ECONOMIC AND SOCIAL COMMISSION FOR ASIA AND THE PACIFIC

Committee for Co-ordination of Investigations of the Lower Mekong Basin (Democratic Kampuchea, Lao PDR, Thailand and Socialist Republic of Viet-Nam)

PREPARATION OF THEMATIC MAPS ON THE BASIS OF SATELLITE IMAGERY

Information Note by the Secretariat

Table of Contents

INTRODUCTION

The Mekong Committee has participated in the experimental programme for investigating land resources by satellite (NASA, LANDSAT I and II) since the inception of the programme. This report is a summary of results of interpretation work carried out by the Secretariat of the Committee in cooperation with the national government offices concerned in the four riparian countries and with the assistance of the French government.

THEMATIC MAPS BASED ON SATELLITE IMAGERY

*****

I. Purpose

The main themes of the maps are:

- Land Use
- Pedo-geomorphology
- Land Capability

The maps are prepared by interpretation of data supplied by the LANDSAT I (also called ERTS-I) and LANDSAT II satellites and from documents, maps, and aerial photographs already available at the Secretariat or in the various government offices of the four Mekong riparian states.

II. Coverage

The study covers the lower Mekong basin, an area of over 600,000 sq. km which includes:

- all of the Lao People's Democratic Republic, though no satellite data are available from the northern extremity of the country;
- most of Democratic Kampuchea with the exception of the south-western areas draining into the Gulf of Thailand;
- the northeast provinces and the northern extreme of Thailand, as well as a small portion of the southeast;
- the Mekong delta area and part of the southern highlands (Ban Me Thuot-Pleiku-Kontum) of the Socialist Republic of Viet-Nam.

III. Satellite imagery

Each frame of satellite imagery corresponds to an area of 180 x 180 km, the whole Mekong basin being covered by 36 frames. The same area is covered every 18 days in four wave bands of the MSS multispectral scanner: MSS 4: 0.5 to 0.6 μ ; MSS 5: 0.6 to 0.7 μ; MSS 6: 0.7 to 0.8 μ; MSS 7: 0.8 to 1.1 μ.

/The working

The working material used corresponded to black and white positive transparencies at the scale of 1:1,000,000 in the various bands. A few photographic enlargements at a scale of 1:500,000 were also prepared (primarily for bands 5 and 7 of the LANDSAT I satellite) as well as numerous composite colour transparencies at a scale of 1:1,000,000 obtained by the superimposition of bands 4 (yellow), 5 (magenta), and 7 (blue) monochromatic positive transparencies at the same scale.

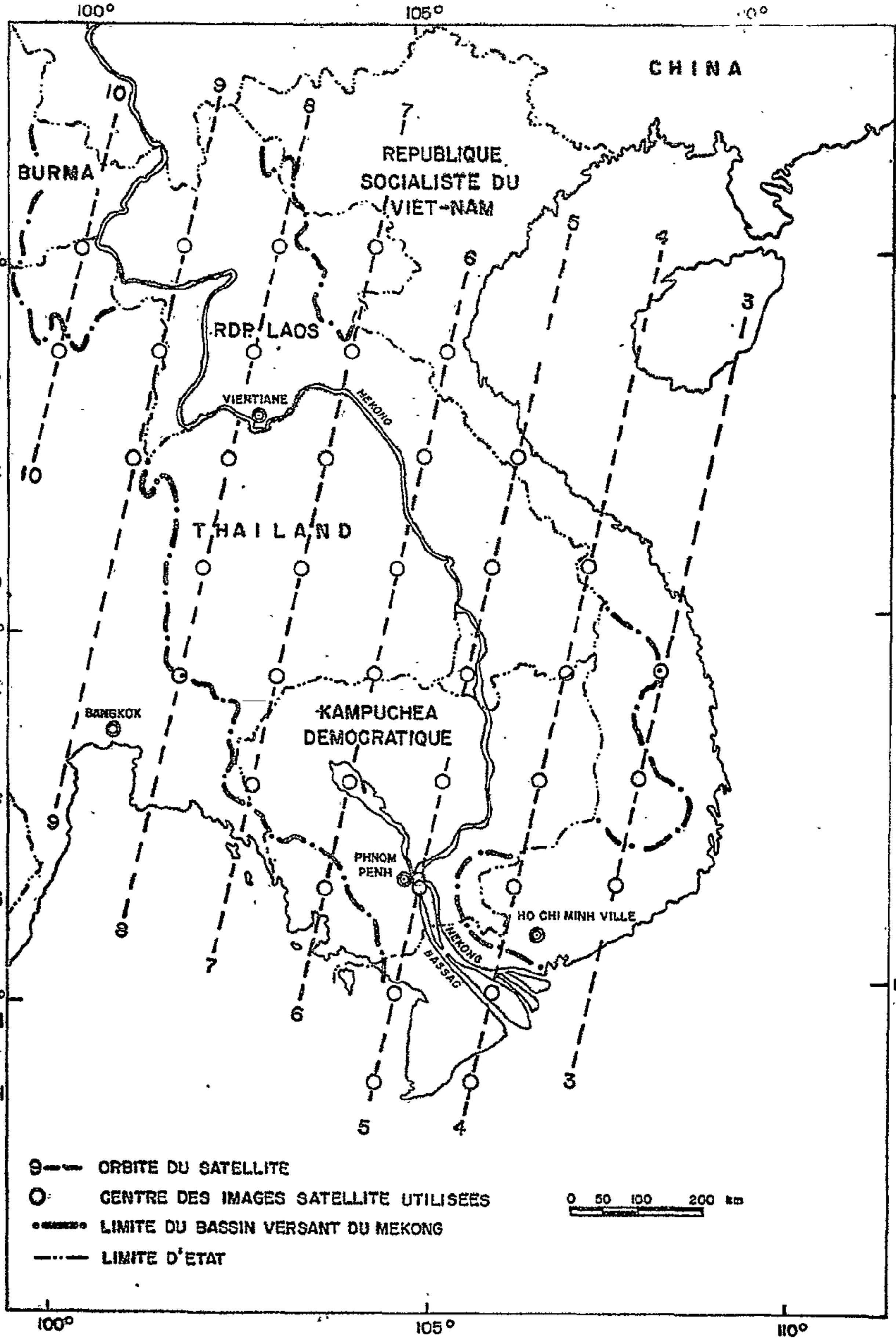
Band 4 images, which have poor contrast, are generally of little use by themselves. Band 5 images give better contrasts and shades for the study of the vegetation cover. Interpretation of band 6 and 7 images can give an idea of geomorphology, soil humidity, and the hydrographic network.

Unfortunately, numerous frames are rendered partly or totally unuseable because of cloud cover, especially during the rainy season.

The Land Use Map was first prepared on the basis of data supplied by the LANDSAT I satellite (1972-1973). Subsequent LANDSAT II imagery (1975-1976) proved of better quality and these were the images primarily used to prepare the Pedo-geomorphologic Map. The Land Capability Map was prepared on the basis of the Pedo-geomorphologic Map.

As might be expected, the quality of images from an area as extensive and varied as the Mekong basin varies greatly from one area to another. Data obtained under the best conditions from some regions can hardly be extended to the entire area. Ground truth controls are required, but these have not yet been carried out. Therefore, legends given on the maps have only an average representative value as regards the whole basin.

/IV.



CHINA
BURMA
REPUBLIQUE SOCIALISTE DU VIET-NAM
RDP LAOS
VIENTIANE
MEKONG
THAILAND
BANGKOK
KAMPUCHEA DEMOCRATIQUE
PHNOM PENH
HO CHI MINH VILLE
BASSAC
100°
105°
110°
20°
15°
10°
A
B
C
D
E
F
G
H
I
ORBITE DU SATELLITE
CENTRE DES IMAGES SATELLITE UTILISEES
LIMITE DU BASSIN VERSANT DU MEKONG
LIMITE D'ETAT
0 50 100 200 km

IV. Map Scale

The original plan of operations provided for a working scale of 1:500,000, but in view of unsolved incertainties and control difficulties it was found that the 1:1,000,000 scale was more appropriate. The results of the study have been plotted on a 1:1,000,000 topographic base map obtained by reduction of 1:500,000 topographic maps (Tactical Pilotage Chart).

/A.

A. LAND USE MAP

I. Interpretation of satellite imagery

The Land Use Map is based on an interpretation of images provided by bands 5 and 7 of the LANDSAT I satellite. Since chlorophyll is characterized by a very high absorption at 0.64 μ, the dark shades appearing on band 5 transparencies correspond to the density and the nature of the vegetation cover. In view of their periodicity, available images can be used to study how the vegetational cover changes from one season to the other, differentiating clearly between evergreen and deciduous forest types. Band 7 has been used to differentiate vegetational groups usually associated with hydromorphic soils.

As for as land use is concerned, the best results are given by interpretation of images corresponding to the dry season, i.e., from January to March. The months of February and March give the best results since deciduous forest types during this period have the highest percentage of species which have shed their leaves, making the contrast between deciduous and evergreen types more evident. For the same reason, differentiation between natural evergreen and deciduous forests on the one hand and between cleared and cultivated zones on the other is at its best in the dry season. The study of the vegetation cover in the dry season is also facilitated by the clearness of the pictures due to the absence of clouds, the abundance of which during the rainy season is a major obstacle.

Moreover, the variety of shades observed on dry season images is much wider than during the rainy season when the luxuriance of the vegetation reaches such a stage that the various vegetational units take a uniform green pattern, appearing as very similar shades on the images (dark on black and white transparencies and red on colour composite transparencies) and preventing a proper interpretation of the vegetation cover.

/The study

The study of satellite data make it possible to prepare a map of the vegetation on an essentially physionomic basis.

II. Description of vegetation units. Reference documents.

For the physionomic description of the vegetational units, we relied on the fundamental research work of J. Vidal (La végétation du Laos, 1960), M. Schmid (Végétation du Viêt-Nam, 1974), and P. Legris and F. Blasco (Notice de la carte du tapis végétation du Cambodge, 1972). The description of some of the units was completed by ground observations carried out in the Thai part of the basin.

III. Ground control

Ground control or verification was carried out mainly on the basis of aerial photographs and maps made available by the national offices concerned in the four riparian countries. Though this information was often rather old (1954 to 1960), comparison with satellite data made it possible to update vegetational units in a generally precise manner. The early maps and aerial photographs were also used to prepare the maps of areas for which only poor quality images were available. The updating, in this case, lacks precision, especially for the province of Loei in Thailand and for the areas located west of the Mekong between Luang Prabang and Paklay in Lao PDR.

In some areas, the absence of any documentation and the impossibility of carrying out ground truth observations made it difficult to identify and describe vegetational formations, as in the northern part of Lao PDR and the areas located north-east of Thakhek.

Ground truth controls were carried out in the north-eastern provinces of Thailand but they were rather limited.

IV. Vegetation units

/4.1

4.1 Dense and mainly evergreen forests

Evergreen forest is composed of leafy trees with crowns that form a continuous canopy above the ground. The forests are composed of fully evergreen stands or of evergreen stands mixed with partially deciduous stands which, as a whole, retain their evergreen characteristics since on the one hand the period when trees are without leaves is short and on the other hand, the deciduous species shed their leaves at different periods.

These units correspond to the darkest shades given by band 5 images (water excepted) and which appear with practically the same intensity over the whole time series of images. The slight variations which appear in some places seem to result either from a different floristic composition, from a low natural density of the vegetation cover, or from the beginning of forest degradation. They can also result from differences in illumination conditions due to time or topography. These variations have too limited areas and too uncertain borders to be mapped.

4.2 Mainly evergreen forests, degraded

Many evergreen forests in the basin are more or less seriously degraded by cutting or by recent or old clearings which replace the forest with temporary or permanent rainfed crops. Depending on the cropping system in use and its intensity, variegated secondary formations (grasses, bamboos, shrubs, and secondary tree formations) occupy more or less extensive areas. Their density typically depends on their stage of development. The presence of evergreen species and the gradation in the leaf-drop of deciduous species give these secondary formations an evergreen aspect which is more evident during the rainy season.

The representation of this vegetational unit on band 5 transparencies is characterized by a very large gamut of gray shades going from light to dark. These shades correspond to the various phases of forest degradation, the various degrees of evolution of secondary formations,

/and

and the extent of cultivated areas. The lighter shades of gray correspond to intensively cleared and cultivated areas. The darker shades represent cleared areas where a more or less dense tree cover or important secondary formations still remain.

On satellite pictures, these units are not always easily distinguished from the undegraded dense and mainly evergreen forests. The distinction is all the more difficult when degradation is less accentuated or when the secondary vegetation has reached an advanced stage. Since all vegetation phases appear between this unit and the previous one, their distinction often involves a large part of subjective evaluation.

4.3 Note on the semi-dense forest or mixed deciduous forest

Vegetation maps of the Mekong basin distinguish an important vegetation unit which, in view of its aspect and floristic characteristics, stands as a transitional type between the dense evergreen forest and the open deciduous forest. These woodlands are mainly composed of deciduous trees shedding their leaves over a very short period. Some 90 per cent of the species lose their leaves and for some 55 per cent of these the leafless period is shorter than a month. The monthly rate of leaf-drop reaches a maximum in February (85 per cent) (Ref. 1). On dry season images, this type of forest corresponds in general to dark shades, most of the time rather similar to the gray shades given by degraded dense forests. It is only during a short period in February when most of the species are leafless that the shades tend to merge with the lighter shades of the open deciduous forest. Because of the dense and generally thick undergrowth, shades however tend to remain darker. These changes in shades are often difficult to differentiate, requiring a study of the whole time series and satellite images of good quality. This type of forest is all the more difficult to categorize through an interpretation of satellite images; it can, according to regions and for physionomic reasons, look very similar either to dense and mainly evergreen forests or to open deciduous forests. While a distinction may be made in a few areas, it cannot be extended to the whole basin.

/In view

In view of its physionmic characteristics, this vegetation unit can correspond to various stages of degradation and cannot in general be differentiated from units 1 or 2.

4.4 Open and mainly deciduous forest

Forests corresponding to this unit are characterized by trees with crowns rarely touching and an herbaceous ground cover with reduced or non-existent brush wood. As a whole, this formation can compare with low density forest although dense stands are found in some places. It can appear as a "dwarf forest" or as a tall-tree forest. During the dry season, it is often subjected to brush-fires which burn the grass cover.

Some 85 per cent of these forests are comprised of deciduous species, a large number of which lose their leaves over a long period (the period without leaves for 70 per cent of these is above one month). The highest percentage of leafless species is reached in February (85 per cent) (ref. 1). Since most of these species belong to the family Dipterocarpaceae, this unit is generally known as Dry Dipterocarp forest.

In view of its physionomic characteristics, this type of forest can easily be identified on dry season pictures. During this period, it corresponds in general to the light gray shades of band 5, in marked contrast with the darker shades of dense and evergreen forests. The various shades of grey correspond in general to differences in density of the tree cover. Areas burnt by fire are represented by very dark patches.

4.5 Open and mainly deciduous forest, degraded

This unit corresponds to areas having a sufficiently important tree cover to give a visible and mappable imprint on satellite pictures, even when fully occupied by crops.

/A11

All stages of clearing and agricultural takeover can appear in open forests. These correspond to the various shades of gray, becoming lighter as the tree cover is increasingly degraded and crops occupy a larger area. It is sometimes difficult to determine the extent of the degradation in this type of open forest and the delimitation of this area involves a large part of subjective evaluation.

4.6 Savanna and well-drained shrublands.

The vegetation in this unit is composed either of grassy formations, scattered shrubs, or a mixture of these two formations. Tall or dwarf tree formations are scattered or non-existent. This unit corresponds in general to the lightest shades of grey in band 5. The extent of cultivated areas cannot be determined since they too have a strong radiance.

4.7 Woody and shrubby vegetation (Thakhek limestone area)

The Thakhek calcareaous limestone area constitutes a remarkable unit where the following two formations are found: on rocks, a craggy bush vegetation which loses most of its leaves during the dry season; and on limestone screes which have built up at the foot of the cliffs, a dense forest. Dark shades of grey which characterize this region are attributed to outcropping limestones on which vegetation is very poor or non-existent.

4.8 Open mosaic vegetation.

This unit groups a number of heterogeneous vegetation formations which can hardly be distinguished from each other since they give closely similar radiances on satellite pictures. They correspond to a mosaic of open, evergreen or deciduous forests (generally very degraded), coniferous woodlands, bamboo forests, secondary formations, or more or less woody savanna and croplands.

/These

These formations have been mapped mainly in the mountainous regions of northern Laos. Their description is difficult, since no ground truth control could be carried out with the exception of a very few limited areas for which photographs are available.

On dry season images (band 5), this unit corresponds in general to a dark grey to light grey background with very similar radiances and very uncertain limits.

4.9 Croplands

Under this unit are mapped regions characterized by a high percentage of cultivated areas and by the paucity of woody or bushy cover. It includes rainfed and irrigated croplands as well as orchards. Secondary formations (brush, grasses) can be rather important, especially in the uplands.

On dry season images, harvested ricefields have a high radiance which is all the more apparent because the soils are dry. In band 5 these generally correspond to very light grey shades. Rainfed crops which are usually closely interspersed with fallow lands occupied by secondary formations give grey shades which depend upon the vegetative condition of crops and the density of secondary formations. Harvested ricefields and rainfed crops can be differentiated on some good quality pictures, but LANDSAT I pictures are not good enough to extend this distinction to the entire basin.

4.10 Large rubber plantations

A small percentage of cultivated lands is covered by tree plantations, of which rubber plantations are the most important in the Mekong basin. Various other tree plantations exist in the basin, but these could not be seen since they are of a limited extent and their characteristics are very similar to those of the surrounding areas.

/4.11

4.11 Woody vegetation and seasonally flooded areas

Woody formations corresponding to this unit are typical of hydromorphic soils which seasonally are partially or totally covered by a layer of fresh water of varying depth. These correspond to moderate or poor woodland forming low thickets with nearly touching crowns in some places. Because of excessive lumbering, this unit nowadays is in most cases represented only by bushes. These formations are particularly well represented in Kampuchea and in some depressions along the Mekong.

In band 5 pictures, these forests give in general very dark shades. They represent the vegetational cover but also, to a large extent, the very significant hydromorphy of the soils.

4.12 Grassy vegetation and shrubs of hydromorphis areas

In poorly drained areas, in swampy depressions, and on hydromorphic soils in general, whether these are permanently flooded or not, there appears a grassy vegetation with shrubs which could result from the degradation of flooded forests. Because of the absence or the paucity of a woody strata, and of a less extensive hydromorphy, the grey shades in the satellite images are lighter than those corresponding to the previous unit.

4.13 Mangrove

The most extensive mangrove areas appear along the Mekong delta coast. They are composed of a rich vegetational formation which is specific to permanently water-logged soils subjected to tidal inundation. The tree species (*Rhizophora* and *Avicennia*) are highly specialized for life in salt-water areas. In view of the particular conditions under which they grow, these forests are easy to map, forming very dark shades of gray. Defoliation stripes uncovering water-logged soils appear in black colour.

/4.14

4.14 Fresh water mangrove

This formation is specific to more or less water-logged soils with a generally high organic content and high acidity. It is sheltered from the highest tides and the replacement of water is a slow process. The vegetative cover is usually composed of very open evergreen shrubs or low trees, with a high percentage of Melaleuca leucadendron.

On satellite pictures, this formation is not clearly distinguished from mangrove or inundated forests. Considering their extent and the specific ecological conditions under which they grow, we decided to plot them on the map by comparing the LANDSAT data with those of the vegetation map of Viet-Nam published in 1969 by the Dalat Geographic Service.

4.15 Vegetation and altitude

Altitude brings about changes in the structure and especially in the floristic composition of the vegetation cover. In Viet-Nam, M. Schmid (Ref. 2) considers that montane vegetation definitely sets in at an elevation of 1,200 meters. In Laos, J. Vidal (Ref. 1) feels that the montane strata starts at 1,000 meters. Since they are essentially of a floristic nature, the variations caused by altitude are not visible on satellite pictures, but in order to give an approximate idea of the montane sector, the 3,000 foot (about 915 metres) contour line has been drawn on the map.

CONCLUSION

Determined by their aspect, the main vegetation units of the lower Mekong basin and the land development conditions have been mapped by interpretation of LANDSAT-1 data. By interpretation of the various shades of gray observed on satellite images, it was possible to map the density of the vegetation cover. The study of their seasonal variations makes it possible to distinguish between mainly evergreen and mainly deciduous forests. In the Mekong basin area, these are generally related to the density of the vegetation cover.

/Man's

Man's intervention, through the changes it brings to the vegetation cover, is visible on satellite images, though the various phases of this activity are sometimes difficult to make out and can thus be a source of confusion in the mapping of vegetational units.

In view of the absence of documentation, the impossibility of carrying out ground truth control, and the often poor quality of some satellite pictures, it was impossible to give all the precision required to the map and to the descriptions of vegetation units in some areas.

Considering the extent and the diversity of the lower Mekong basin, we do not claim that the best possible use has been made of available satellite pictures, but a more precise and more detailed study would require more intensive ground truth control which was not possible when these maps were prepared.

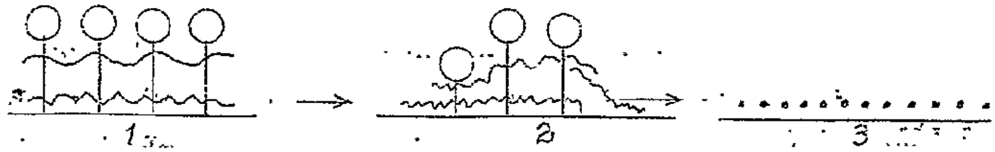
VI. Annex: Dynamics of vegetation succession

The notes and drawings presented in this annex were communicated by J. Boulbet (Ecole Française d'Extrême Orient). These notes constitute an excellent guideline for the understanding of the vegetation cover, and we thank Mr. Boulbet for sharing his long experience in the Mekong countries with us.

6.1 Regressive evolution

6.1.1 Degradation through regular or traditional clearing

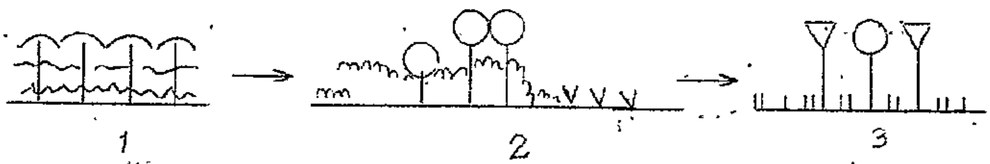
The following schematic drawings illustrate the stages in vegetation succession through which the vegetation evolves from mature climax forest to various forms of degraded vegetation.



1. Dense stands of tall trees with an evergreen tendency, hygrophilous. Height = 35-50 m

2. Cleared fallow land; develops from thicket to copes to secondary forest with an evergreen tendency. Height 1-35 m

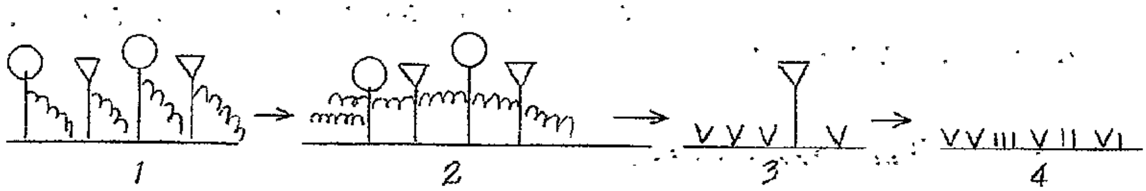
3. Anthropic savanna (Imperata, Eupatorium) + shrubs and thickets



1. Medium evergreen dense stands appearing on hills or medium elevations. Heights 25-35 m

2. Forest fallow lands evolve from thicket to secondary dense evergreen forest. Height = 1-25 m. Bamboo forest: Height 1-15 m

3. Mixed pole stage forest (semi-dense, semi-deciduous intrusions). Height = 1-20 m



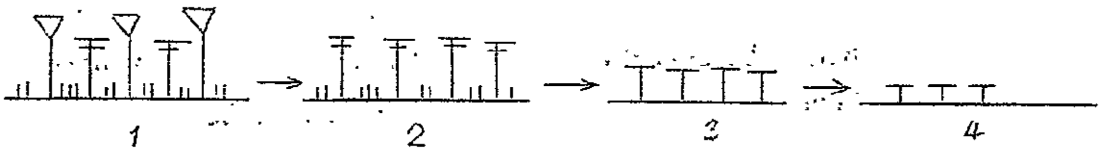
1. Sub-dry deciduous forest with mixed intrusions (semi-dense and semi-deciduous) with dense galleries. Height = 15-30 m.

2. "rich" open forest with mixed intrusions and dense galleries. Height = 15-25 m.

3. "poor" open forest with graminaceous undergrowth. Height = 10-15 m.

4. Scanty savannah, fragmented with here and there a varying number of trees (special pedo-edaphic conditions). Height= 1-10 m.

6.1.2 Degradation by annual burning (fire-climax)

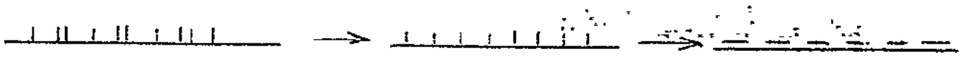


1. Sub-dry deciduous forest with mixed intrusions (semi-dense and semi-deciduous with dense galleries. Height = 15-30 m.

2. "Rich" open forest with mixed intrusions and dense galleries. Height = 15-25 m.

3. "Poor" open forest with graminaceous undergrowth. Height = 10-15 m.

4. Scanty savannah, fragmented with here and there a varying number of trees (special pedo-edaphic conditions). Height 1-10 m.



1. more or less dense pole stage forest (with very localized climates: edge or transition vegetation). Height = 2-10 m.

2. Low pole wood, open and mixed with savannah. Height = 1-5 m.

3. Savannah with thickets and shrub, shrubby step or dotted with shrubby trees. Height = 1-5 m

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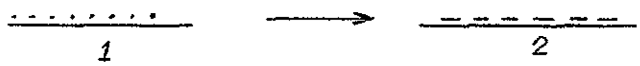
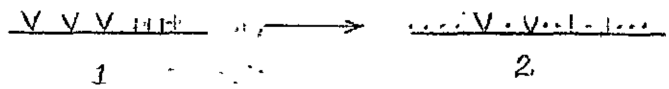
6.1.3 Degradation through clearing and annual burnings



1. anthropic shrubby savannah

2. homogeneous savannah with Imperata



1. open pole wood, open xerophilous bamboo forest

2. discontinous savannah with various Graminaceal and a varying number of scattered trees; intrusions: bamboo growths and open pole wood

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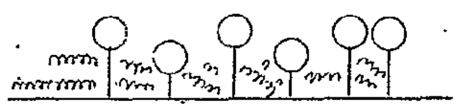
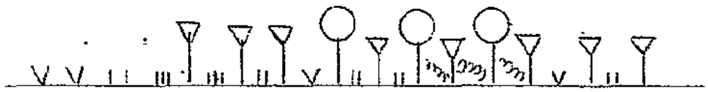
6.2 Progressive evolution

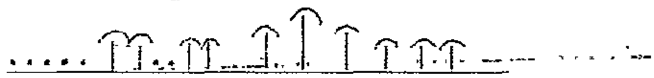


1. dense thicket (formerly cleared and cultivated land now abandoned) to all secondary dense patterns. Height = 1-35 m.

2. from savanna with trees to open "rich" mosaic forest + deciduous semi-dense forest.



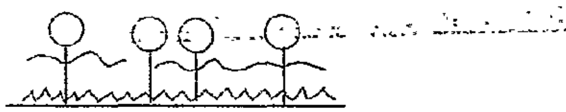
3. from bamboo forest - pole forest to mixed forest or the mosaic bamboo forest + mixed forest + semi-deciduous forest with Lagerstroemia.



4. from savannah with Imperata to shrubby savannah with Eupatorium to brake and secondary forest brake (dense low or medium height secondary forest). Height 1-25 m.

6.3 Definitions

1. Dense and mainly evergreen forests (or with an evergreen tendency)



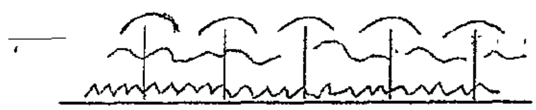
Tall 3-layered stands of forest vegetation with an inter-layer of creepers and epiphytes. According to bio-geographic conditions, the top layer is more or less important, reaching 40, 45 or 50 m but seldom more. This is an irregular layer characterized by emergent dipterocarps (various *Dipterocarpus*, mainly *D. alatus*, plus *Shorea*, *Anisoptera* and *Hopea*), Sterculiaceae (especially *Heritiera javanica*), and giant Meliaceae on basalt soils (red soils). Other species are not typical of this formation (*Irvingia*, *Ficus*, large leguminous plants ....). In contrast to the emergent layer, the main layer is continuous with touching crowns. It is mainly composed of the families Guttiferae, Sapindaceae, Meliaceae, Apocynaceae, Sterculiaceae, Moraceae, Lauraceae, and Myrtaceae.

/Intrusions

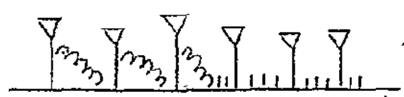
Intrusions of semi-deciduous species are linked to very limited modifications in the bio-geographical environment (general topographic, edaphic and pedologic conditions). These intrusions are characterized by the abundance of some leguminous plants, by the appearance of Lagerstroemiae and Tetramelas, the famous tree with huge buttresses. These intrusions are much too localized to modify the overall aspect of the forest which, as a whole and from a descriptive angle, can reasonably be considered as mainly evergreen.

2. Dense evergreen forest of the hills

This forest is composed of more homogenous but lower stands than the previous type and is composed of less stout trees (except on a few shelves or cultivated valleys). The layers are the same as those of the previous type but are not as well separated. With elevation, the large dipterocarps become scarcer and finally disappear while Lauraceae, Fagaceae, and Magnolaceae take a more important place.



3. Dense semi-deciduous forest

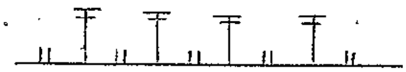


a) Hygrophilous pattern: these are forests with a high layer of emerging trees and often mixed lower layers; the creeper and epiphytous inter-layer is well represented. The upper layer, somewhat less high but more homogenous than in unit 1, is mainly composed of Lagerstromiae, Tetrameles, Pahudia, Ficus and Irvingia. Large dipterocarps appear here and there as intrusions. The sub-stories are evergreen with a large number of creepers.

/b)

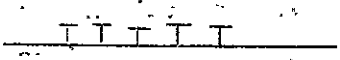
(b) Semi-dense and semi-deciduous ~~patterns:~~ these are homogeneous stands of Lagerstroemia with scattered individuals of the species listed in pattern 3a (plus Ceiba). The undergrowth is comprised of pole trees through which sunlight can pass; the trees are of average height and the shrubs rise with clearly separated stems generally without tangling or overlapping stories which do not create horizontal layers. Creepers and vines may here and there be clearly represented and sometimes attain very large size.

4. Sub-dry deciduous forest or "rich" open forest



The trees of the standard south-Indochina open forest are mixed species which adapt very easily to the environment: Xylia, Dipt. intricatus, D. obtisufolius, Ceiba, Entada creeper, Terminalia, and sometimes Ficus and Irvingia. The undergrowth is either herbaceous or composed of low pole trees with Cratozylon. Here and there appear stands of Corypha palm trees.

5. Open forest or savanna with trees



This is the south-Indochina open forest with Shores obtusa, Pentacme siamensis, Dipterocarpus tuberculatis and Terminalia tomentosa with a graminaceous undergrowth.

/6.

6. <u>Clearings, savannah, prairies or prairie-steppes (discontinuous savanna)</u>

These are climatic herbaceous clearings similar to those found in virgin unaccessible or unhabitated forests, marked here and there by clearings in places where bio-geographic conditions prevent the establishment of a forest cover. Patches, galleries or narrow transitional formations at the edges constitute low pole stands or bushy formations with Myrtaceae and Melastomaceae.

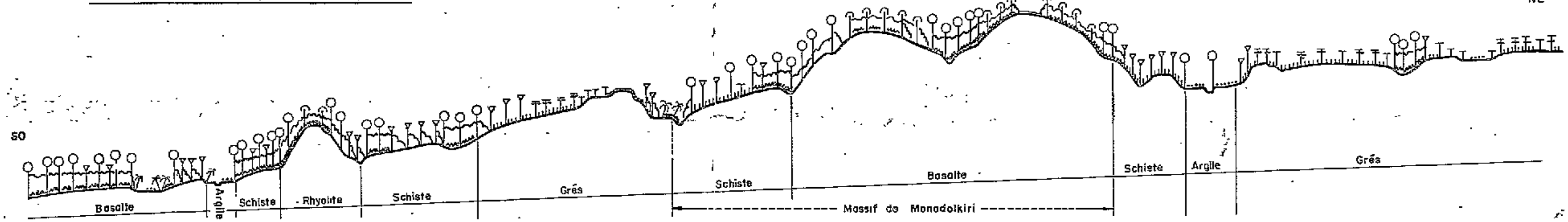
7. <u>Anthropic formations</u>

These are formations which have been largely determined by human activities; they include:

- Dense thickets on former cleared and cropped land which is now abandoned.
- Thick copses and young evergreen forest fallow lands.
- Secondary young dense evergreen forest with undifferentiated layers.
- Stabilized adult secondary forest with more or less differentiated stories; mainly evergreen and dense.
- Pole tree growth (Melastomaceae, Myrtaceae, Cratoxylonae) on land formerly cleared and cropped under marginal or too intensive conditions and now abandoned.
- Anthropic savannah: this is an herbaceous thick and homogenous formation that appears on lands that were formerly too intensively grubbed, burnt or cleared. Often *Imperata*, the main element, is mixed with *Eupatorium* shrubs and Leguminaceae to constitute a "rich" savannah, or with species of the previous pole tree stands to create a "poor" savannah.

/Note

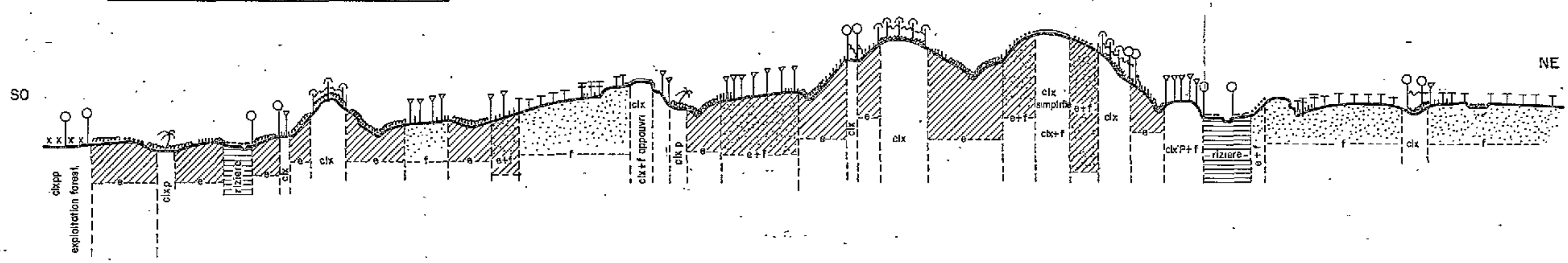
– Reconstitution schématique du climax probable



- Haute futaie dense hygrophile à tendance sempervirente ; h = 40/50 m
- Futaie dense sempervirente collinéenne basse ou moyenne ; h = 25/35 m
- Forêt dense sempervirente de bas-fond (palmiers)
- Forêt dense semi-décidue ; h = 30/40 m
- Forêt mixte (forêt semi-dense, semi-décidue)
- Forêt basse, sub-sèche, décidue ; forêt claire "riche" mêlée de perchis
- Forêt claire "pauvre" ; savane arborée (sous-bois à Graminées) ; h = 10/15 m
- Savane marécageuse
- Clairière herbeuse, savane-steppe

(schéma 1)

– Dégradation anthropique intensifiée du schéma I



Clx = Climax de base (Schéma I)

Clxp = Climax de base perturbé

Clxpp = Climax de base perturbé par exploitation forestière industrielle

e = Dégradation par essartage

f = Dégradation par le feu ; équilibre pyro-climacique

= Savane climacique (– Id schéma I)

= Savane anthropique + fourrés (+ ou – xérophiles)

= Rizière

(schéma II)

Note

The "mosaic" vegetation stands where various formations are interspersed in patches or fingerlike formations with a complicated design, or are mixed in such a manner that no formation clearly predominates, are schematically represented by intercalation of the symbol of each of the respective formations.

Conclusion

The separation between mainly evergreen forests and mainly deciduous forests through interpretation of satellite imagery seems to correspond to the separation between hygrophilous patterns and semi-dense and semi-deciduous patterns of the dense semi-deciduous forest.

/B.

B. PEDO-GEOMORPHOLOGIC MAP

The original plan of operation provided for the preparation of a hydro-geomorphologic map. Results obtained in this field are of only limited use in view of our insufficient knowledge of the geology of a large part of the basin and of the impossibility of carrying out ground truth controls. Moreover, the use of satellite imagery for a study of floods is rather restricted during the rainy season because of the very extensive cloud cover, often over very wide areas.

It appeared, however that a pedo-geomorphologic map could very easily be made on the basis of satellite data provided it was prepared through a close comparison with available pedologic documents.

I. Documents used

The pedo-morphologic map was prepared primarily on the basis of 2 types of documents. Satellite pictures were used as the basic data, while pedologic maps and sometimes geological and topographic maps were used as reference documents.

Most of the imagery used was supplied by the LANDSAT-II, including black and white positive transparencies corresponding to the various bands at the 1:1,000,000 scale and composite coloured transparencies at the same scale. The most useful images are from the dry season,especially during the months of February and March. However, the study of all other pictures taken in the course of the year provided a wealth of information, especially for the study of seasonal changes of humidity in the soils.

Main pedological reference documents were:

- the general soil map of the lower Mekong basin 1:1,500,000 (van der Kevie).
- the general soil map of Viet-Nam 1:1,000,000 (F.R. Moormann)

/the general

- the general soil map of Thailand
  1:1,000,000 (F.R. Moormann and S. Rojanasoonthon)
- the general soil map of Cambodia
  1:1,000,000 (C.D. Crocker)
- detailed pedological maps (Thailand)
  1:100,000 - prepared for the various Thai provinces.

Pedologic units are also described on the basis of the bed-rock and the morphology given in:

- the draft geological map of the lower Mekong basin
  1:1,000,000 (unedited) D.R. Workman
- the "carte géologique de reconnaissance de la République khmère"
  1:200,000 BRGM

Various topographic maps at the 1:50,000 and 1:250,000 scales were also consulted.

II. Methodology

The comparative study of available soil maps and satellite data shows that there is often a relationship between the various shades of grey observed on satellite images and the various pedologic units (soil associations) given on the maps. This study makes it possible to improve the delineation of the soil types. Moreover, pedologic units in some of the lesser known regions of the basin can be corrected through a geomorphologic interpretation of satellite imagery.

This methodology brings about a double precision:

- improved delineation of soil units given on previous maps;
- new mapping of some areas which could not be properly studied earlier.

A comparison of figures 1 and 2 shows how pedological maps can be improved with the help of satellite imagery.

/III.

III. Control

Results of interpretation carried out for the preparation of this map were confirmed by ground truth controls in the north-eastern provinces of Thailand.

IV. Description of pedological units

We retained the FAO-UNESCO nomenclature used by W. van der Kevie in the General Soil Map of the lower Mekong basin. (A table of correspondence between the legends of the various documents used in our study is given in the Annex). Soil descriptions have generally been drawn from the descriptive legend which accompanies the above.

Each pedological unit corresponds to a group of soils or to an association of soil groups composed of a major soil group covering more than 50% of the map unit and of 1 or 2 other secondary soil groups (at least 20% each). Soil groups covering less than 20% of the unit are mentioned as inclusions.

4.1 Undifferentiated alluvial soils

These soils are limited to the central part of the Mekong delta. The relief is very flat. The soils are characterized by water-logging or high humidity throughout most of the year.

The various soil categories which appear in the delta on the general soil map of the lower Mekong basin are classified primarily according to their acidity and could not be differentiated through interpretation of satellite images.

4.2 Eutric fluvisols

These are found in recently formed alluvial areas constituting bank levees along the Mekong and on sandy islands in the river. Thin strips of these soils also appear along most rivers, though these are often too narrow to be shown on a map. Their extent may be more important when gradual or rapid shifting of the rivers has taken place.

/Series

Series of natural levees are then formed, interceded by low-lying areas that are sometimes marshy and often hydromorphous. These soils do not appear in the lower part of the Mekong where tidal influence is felt, increasing in importance towards Kampuchea. The relief, which is in general slightly undulating, varies from less than a meter to a few meters above the level of surrounding alluvial formations. These soils can be flooded for short periods at the peak of the rainy season, but being located somewhat higher than the water level, they are typically well drained.

Eutric fulvisols are developed in coarse alluvium left by water when flooding over riverbanks. Their texture varies from loam to clayey loam. They have no diagnostic horizon, but in exceptional cases a light horizon can be seen. Hydromorphy is low. The organic matter content varies with the profile, but is generally low.

Inclusions are essentially composed of eutric and mollic gleysoils localized on more poorly drained alluvia found in depressions along the banks.

On satellite pictures, alluvial levees appear clearly when they are sufficiently large. They correspond to light grey shades contrasting with the dark grey of the very humid lowlands which usually border them.

4.3 . <u>Eutric fluvisols, saline phase, associated with eutric gleysols</u>

These soils are found mainly in depressions subjected to tidal influences and located between fossil beaches in the Mekong delta. They are partly flooded by brackish water during high tides and sometimes by sea water for part of the year. Drainage is rather poor.

These depressions, which are always water-logged or very humid, appear clearly on dry season satellite images. Their very dark shades in Band 7 contrast with the very light shades of fossil beaches. However, these soils are difficult to distinguish when they occur in very humid flat areas where there is no alternation between fossil beaches and depressions.

/These

These soils are totally different from the previously described eutric fluvisols because of their generally clayey texture and their poor drainage. Their profile is weakly developed with spots in the upper part, and they have a deoxydized and loose clay horizon at shallow depth. The A horizon has a dark grey colour while the next horizon is grey. These soils vary from moderately acid to neutral.

They are associated with eutric gley soils that have a somewhat better developed profile. The deoxydized and loose clay horizon appears at a greater depth and has a fine polyhedric structure.

Inclusions are thionic fluvisols and gleyic cambisols localized on old fossil beaches.

4.4 Thionic fluvisols

These soils are mainly found in the low areas of the Mekong delta (Plain of Reeds in the east, Hatien-Rach Gia depression in the west). During the rainy season flooding is very important; in the dry season water may recede for a short period over limited areas, but the soils remain water-logged.

Very extensive areas of these soils are always waterlogged, uncultivated, and generally covered with reeds or other swampy vegetation, and they can easily be mapped on the basis of dry season satellite data. The delineation of thionic fluvisols is more difficult when these characteristics do not appear on images; in such cases they have been included in undifferentiated alluvial soils.

These soils, which are also known as "terres alunées" (catclays), are formed on brackish sediments containing variable quantities of iron sulphides. They have a clayey texture. The A horizon, which is thick and varies from very dark grey to black, lies on grey to greyish-brown clays with large brownish-yellow to light yellow patches. They have a weak to moderate polyhedric structure. This horizon is found at a

/shallow

shallow depth on deoxydized and muddy clays of a dark grey colour. Thionic fluvisols are characterized by a very strong acidity (pH from 2 to 3.5, sometimes even lower than 2 when dry) even in the upper horizon. Acidity, however, is far from uniform and important variations are found within a distance of a few hundred meters.

Inclusions: slightly less acid humic gleysols.

4.5 Thionic fluvisols, associated with humic Gleysols

Satellite images show an area with rather homogenous configuration and very flat topography, which limits the Mekong delta in the north and differs from unit 1 by a less predominant water logging or humidity during the rainy season and a much drier condition during the dry season. This area corresponds approximately to thionic fluvisols associated with gleysols mentioned in the general soil map of the lower Mekong basin.

These are clayey and poorly drained soils lying on brackish alluvium. The A horizon, which is thick and of a very dark grey colour, lies on a clayey and deep B horizon with a grey to greyish-brown colour and with yellow and or yellowish-brown mottles. Most have a low pH which is in general below 3.5 at 100 cm below the surface. However, extensive areas which are somewhat less acid, and which could be related to humic gley-sols, have been included in this mapping unit.

4.6 Eutric Gleysols

These are formed in poorly or insufficiently drained river backswamps as well as in the flood plain of the Great Lake. During the rainy season, wide and extensive flooding takes place.

This soil unit can easily be identified on satellite imagery because of its generally dark grey colour resulting from its significant humidity, the naturally dark colour of the soils, and the flooding which characterizes these depressions.

/The eutric

The eutric gleysols are clayey, their colour varying from grey to brownish-grey with large brown or brownish-yellow spots. Horizon A is dark grey or dark brownish-grey. Horizon B is deep and well structured. These soils dry deeply during the dry season and often show such characteristics of vertisols as deep cracks. Their pH varies from acid to neutral. Base saturation is higher than 50%.

4.7 Eutric gleysols associated with Mollic Gleysols

These soils include most of the recent alluvial deposits in depressions located along the banks of the Mekong in the upper part of the delta and nearly up to Kratie. They are deeply flooded for a longer period than the unit considered above, and are water-logged almost throughout the year.

They can be differentiated on satellite imagery because of their characteristics resulting from a more extensive surface hydrology. They are clayey with a generally grey colour and important yellowish-brown to brown spots. They are characterized by a very dark upper horizon. The pH varies from very acid to slightly acid but the base saturation is above 50%.

Intrusions include humic gleysols with a very dark upper horizon, a more acid reaction, and a lower base saturation and thionic fluvisols with a very acid "catclay" clayey horizon.

4.8 Mollic Gleysols

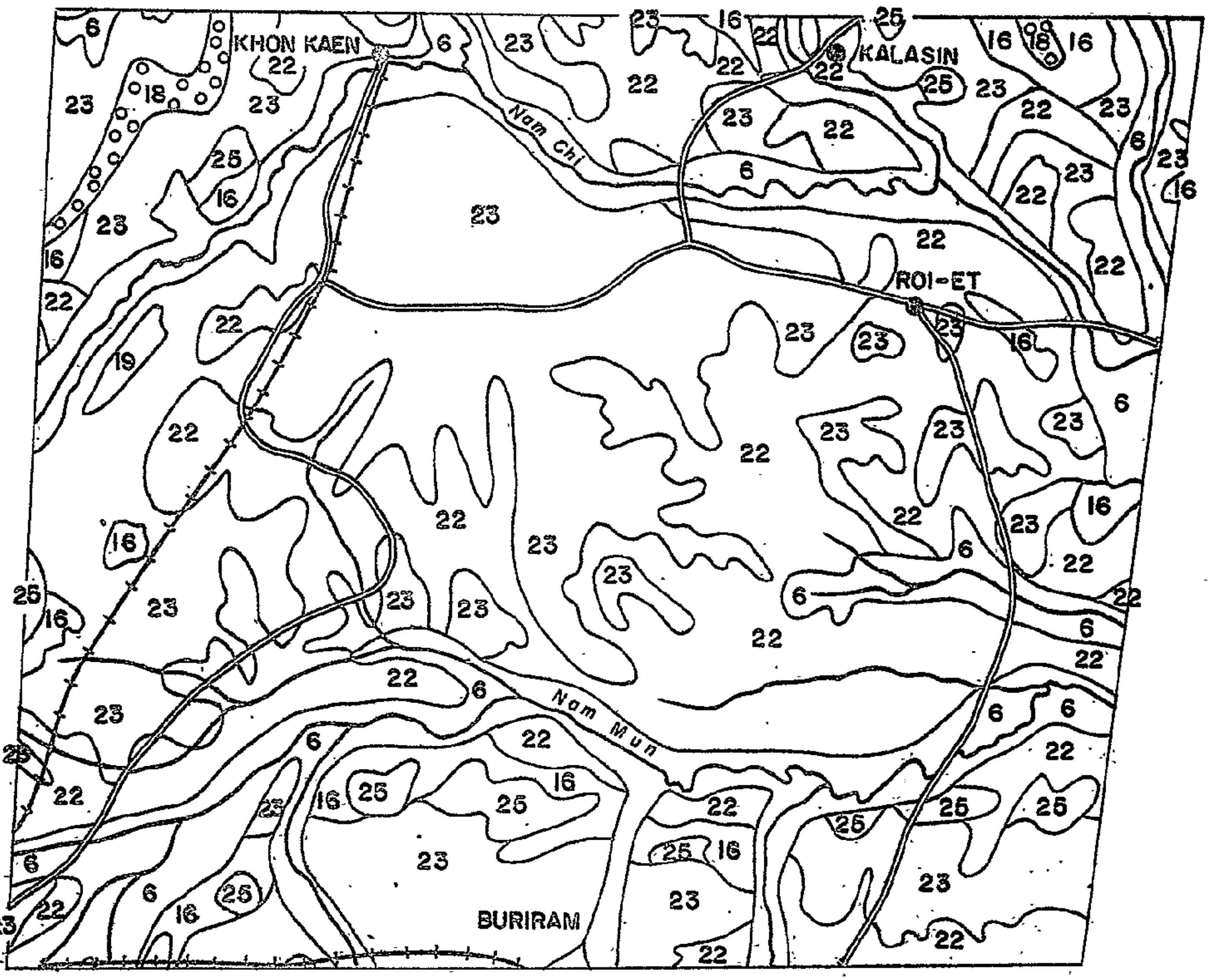
These soils appear in old or recent fossil beaches of the Mekong delta. The relief is in general rather flat with a more accentuated micro-relief in a few areas. Though submerged by rain water which accumulates in rice fields during the rainy season, these soils are not flooded by river water. During the dry season, they differ by their drier aspect from undifferentiated alluvial soils which are always wet.

/Dry season

AGRANDISSEMENT de la CARTE GENERALE des SOLS du BASSIN INFERIEUR du MEKONG

REGION DE LA NAM MUN – NAM CHI

Echelle 1: 1.000.000



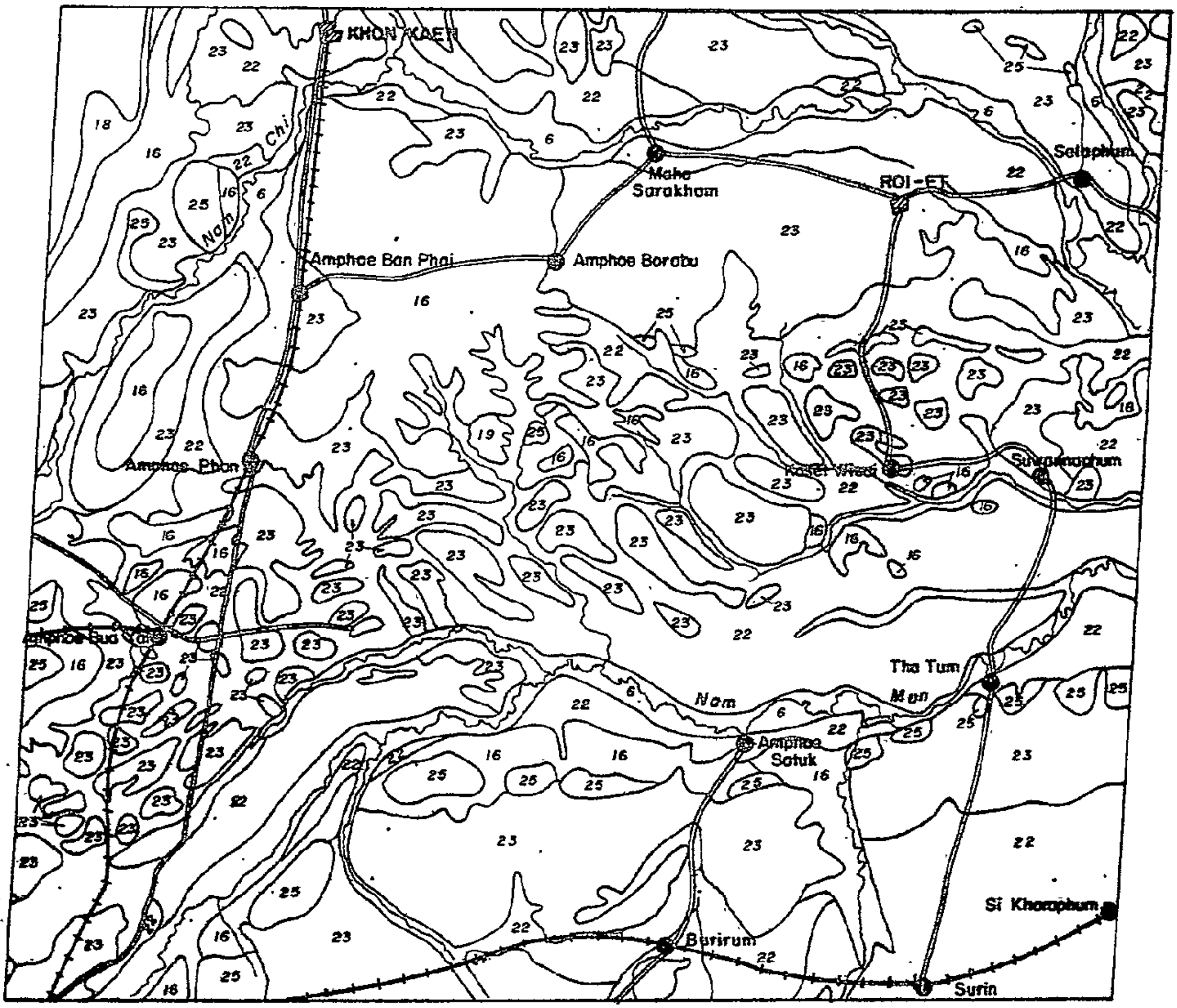
LEGENDE

6	EUTRIC GLEYSOLS
16	FERRALIC CAMBISOLS ASSOCIES A DES FERRIC ACRISOLS
18	ORTHIC ACRISOLS ASSOCIES A DES LITHOSOLS
19	ORTHIC ACRISOLS ASSOCIES A DES DYSTRIC NITOSOLS ET DES FERRALIC CAMBISOLS
22	GLEYIC ACRISOLS ASSOCIES A DES DYSTRIC PLANOSOLS
23	GLEYIC ACRISOLS ASSOCIES A DES FERRALIC CAMBISOLS ET DES FERRIC ACRISOLS
25	ORTHIC FERRALSOLS

INTERPRETATION des IMAGES du SATELLITE

REGION DE LA NAM MUN - NAM CHI

Echelle 1: 1.000.000



LEGENDE

6	EUTRIC GLEYSOLS
16	FERRALIC CAMBISOLS ASSOCIES A DES FERRIC ACRISOLS
18	ORTHIC ACRISOLS ASSOCIES A DES LITHOSOLS
19	ORTHIC ACRISOLS ASSOCIES A DES DYSTRIC NITOSOLS ET DES FERRALIC CAMBISOLS
22	GLEYIC ACRISOLS ASSOCIES A DES DYSTRIC PLANOSOLS
23	GLEYIC ACRISOLS ASSOCIES A DES FERRALIC CAMBISOLS ET DES FERRIC ACRISOLS
25	ORTHIC FERRALSOLS

FIGURE II

Dry season satellite pictures give the best results for their mapping. Mollic gleysols seem to correspond to the lightest shades observed in the delta. These result, inter alia, from the nature of the soil, its low humidity, its low or non-existent tree cover, and the extensive occupation of the soil by rice fields that have been harvested in this time of the year. Moreover, fossil beaches on which these generally appear can easily be identified because of their specific orientation.

Mollic gleysols are clayey and poorly drained; their colour varies from greyish-brown to reddish-grey with an upper horizon varying from very dark grey to dark reddish-brown. Lower horizons show numerous reddish-yellow to brown mottles. The B horizon is well developed with moderately developed fine polyhedric structures. Reduction seems to take place below 150 cm. The pH varies from slightly acid to moderately alkaline. These soils can be slightly saline in the lower horizons.

Inclusions include eutric gleysols, eutric fluvisols and some gleyic cambisols localized on ridges with a loamy texture.

4.9 Humic gleysols, associated with distric gleysols, petric phase

These are typical of the plains located north-east of Snoul (Kratie and Mondol Kiri provinces). They are water-logged during the rainy season and remain humid during the dry season. The tree cover usually forms dense forest.

These are dark clayey soils. They are rather shallow and lay on a very hard lateritic pan. The upper horizon contains a large number of ferruginous concretions. The pH is low, as is the base saturation rate. Drainage is non-existent or very poor.

/4.10

4.10 Lithosols associated with haplic phaeozems

This unit includes very shallow soils on basalt plateaus and limestone hills. The topography is variable and usually very accentuated (rolling or with steep slopes and escarpments). The soil cover is often eroded, and the bed rock appears at ground level or immediately below.

Their mapping is based on the geology indicated in various documents and on the topography observed on satellite imagery.

Most of the soils of this unit have a depth of less than 10 cm. However, stony and deeper soils of a dark colour and with a brittle surface are often found, especially on basalts. They have a clayey to clayey-loamy texture. The pH varies from neutral to basic. The base saturation rate is high.

Inclusions are pellic vertisols, calcaric cambisols and redzines.

4.11 Luvic arenosols

Those are mainly formed on sandstones, granites and rhyolites which, when weathered, give a sandy material ensuring very good drainage. The topography is irregular: flat to rolling (more or less eroded plateaus; areas occupied by elongated low ridges) or with a large number of low hills.

On satellite pictures, these cannot be distinguished from the surrounding ferric acrisols associated with plinthic acricols (unit 21). These two soil units have a low fertility and are usually covered by open dipterocarp forests.

Luvic arenosols are very sandy; their colour varies from yellowish to brownish. Their organic matter content and their exchange capacity are very low. Drainage is excessive and the water holding capacity very low. These soils can be stony.

/4.12

4.12 Rendzinas associated with pellic vertisols and calcaric cambisols

These soils appear on limestone colluvium and on marl in practically flat areas. This unit is mainly constituted by shallow and black redzines. The upper horizon, which is black, clayey, granular and varies from neutral to basic, has a thickness of 20 to 50 cm. It lays on a marly and gravelly horizon (basic pH).

In the lowest areas, these are generally associated with pellic vertisols which are deeper, have a clayey structure, and are less brittle (though the upper structure is sometimes granular). These soils are very sticky when wet and very hard when dry; they show deep cracks during the dry season. The A horizon, deep, black to very dark grey, lies on soft marls or calcic clays: The exchange capacity and base saturation are high.

Inclusions: chromic cambisols and lithosols on limestone, shallow or moderately deep, reddish-brown, deep and brittle dystric nitosols.

4.13 Pellic vertisols associated with chromic vertisols

These are essentially formed on basalt bed-rock with an almost flat or slightly undulating relief. In Kampuchea they are found around the Kompong Cham and the Kratie basaltic ranges as well as in depressions and flat areas of the mountainous regions of Mondol Kiri and Ratana Kiri. Small outcrops also appear in the north-east of Thailand.

The vegetational cover found in this unit is generally a more or less degraded, mainly evergreen dense forest.

Pellic vertisols have a thick (20 to 40 cm) clayey, black or very dark A horizon with mottles and ferruginous concretions. Though generally granular, the structure is polyhedric. The pH varies from acid to neutral. These soils lay on dark-reddish brown clays with a neutral to alcaline pH, and a large number of ferruginous concretions. They are composed of montmorillonitic clays which swell strongly when wet and retract when dry, revealing cracks and deep retraction fissures.

/They

They are very sticky when wet and difficult to work. Most of the pellic vertisols are badly drained.

Somewhat better drained, brown to dark brown chromic vertisols are found in higher areas.

4.14 Gleyic solonchaks associated with thionic fluvisols and eutric fluvisols

These are found along the delta coast in permanently waterlogged areas subjected to tidal influences. Very poorly drained and highly saline, they are characterized by mangroves which facilitates their mapping. Gleyic solonchaks are composed of fully deoxydized muddy clays. Associated with these are:

- thionic fluvisols: potentially acid and with a high sulphur content, these become extremely acid when drained;
- eutric fluvisols: poorly drained, they are differentiated from gleyic solonchaks by their low salinity (conductivity lower than 15 mmhos).

4.15 Gleyic cambisols associated with gleyic luvisols

These occur on the ridges of old or recent fossil beaches where they appear as narrow strips normally used by human settlements and thus sheltered from floods.

Gleyic cambisols are young soils with a practically undifferentiated profile. They have a loamy structure. The greyish-brown to brown A horizon lays on a yellowish-brown to brown or dark-brown B horizon with light mottles. Horizon C is light grey to light greyish brown. The organic matter content is very low. The pH varies from acid to neutral. Some of these soils may have a low salinity. Drainage is normally quite good. Gleyic cambisols are surrounded by clayey gleysols or fluvisols formed on marine deposits.

/Associated

Associated gleyic luvisols have similar characteristics but are found on older fossil beaches. These are characterized by a B horizon with a clayey revetment, the clay content of which is higher than in the upper horizon.

Inclusions: badly drained mollic gleysols, eutric gleysols and very sandy and well drained eutric regosols.

4.16 Ferralic cambisols associated with ferric acrisols

These occur in particular on middle alluvial terraces in the north-east provinces of Thailand. Compared to soils of unit 22, they occupy a higher topographic position; although both units are parts of the same terrace level. They are also found on materials resulting from sandstone decomposition. In Kampuchea they appear on granitic or sandstone bed-rocks, on their colluviums and on older alluvia of the Mekong terraces. Topography, which varies between undulating and highly rolling, is often deeply cut by erosion.

Rainy season satellite images available for some regions make it possible to differentiate these soils from those of unit 22 which are generally flooded or very humid during the wet periods.

Ferralic cambisols are deep and characterized by a sandy loam and greyish-brown A horizon covering a brown or light yellowish-brown, sandy loam or sandy clay-loam B horizon. The clay content increases progressively with depth. Indistinct spots are sometimes found in the lower part of the profile. No alluvial clay is found. The structure is very weak or massive. The alterable mineral content and the exchange capacity are low. These soils are generally acid and have a low organic matter content. Where subjected to a very active alteration between wet and dry, these soils seem to be closely related to ferralsols.

These soils are associated with ferric acrisols which are quite similar to ferralic cambisols. The upper horizon, which is also of the sandy loam type, lies on a sandy clay loam horizon but the B horizon,

/which

which is generally of a pinkish-grey to light-brown colour, shows strong reddish spots and a large number of ferruginous concretions. Clayey revetments are sometimes found.

4.17 Gleyic luvisols associated with orthic luvisols and eutric gleysols

Gleyic luvisols appear in the lower parts of the semi-recent alluvia of northern Thailand and on the colluvium of basic and acid origin constituting the fluviatile plain of Battambang province (Kampuchea).

There are no criteria to differentiate these soils from those of Unit 22 on satellite images and their mapping is mainly based on available pedologic documents.

These are greyish-brown soils with a large number of mottles and a loamy to loamy-clay upper horizon laying on a textural B horizon well developed and characterized by a fine texture and by the presence of clayey revetments. They have a low to medium organic matter content, a low to medium exchange capacity, a high base saturation, and an acid to neutral reaction. Drainage varies from average to poor.

These soils are found in old river backswamps where they are associated with the better drained orthic luvisols of former bank levees and with eutric gleysols in the lowest parts of the depressions.

Inclusions: gleyic acrigols and eutric fluvisols.

4.18 Orthic acrisols, associated with lithosols

Stony and shallow, these soils occur in areas marked by steep slopes (mountains, hills, deeply eroded plateaus) and more generally in areas where the bed-rock is directly or practically outcropping. These are normally observed on intermediate or acid rocks. Where

/geology

geology is not known, however, the study is based only on topography. In the same manner, the map does not differentiate small limestone and basalt areas.

This unit can be delineated through a study of Band 7 images, when it is conditioned by a marked topography. In low and feebly undulating regions, study of multispectral images makes it possible to determine large areas of outcropping or nearly outcropping rocks, because of the scattered and generally deciduous tree cover and the extent of the grassy carpet which dries quickly during the dry season. The shades are grey (outcropping rocks) or light grey (nearly outcropping rocks). It does not seem possible, however, to differentiate in these areas the lateritic pans of the rocks.

Most of these soils are shallow (5 to 30 cm), acid (pH 4.5 to 6.5), with a loamy sand to clayey texture (usually loamy clay). In view of the variety of pedological conditions (topography, nature of the bed-rock, climate), great differences are found within this unit. Soils on granites and rhyolites very often form sandy to sandy loam. Dacites, mica schists, and sedimentary schists give more clayey materials while sandstone often turns into poorly developed sandy soils.

Orthic acrisols are associated with very shallow lithosols (less than 10 cm above the bedrock).

Inclusions: rather young chromic cambisols, without textural B horizon; humic acrisols with a high humus content can be found in the highest hilly areas with high rainfall.

4.19 Orthic acrisols associated with dystric nitosols and ferralic cambisols

These occur on materials resulting from the weathering of various types of rocks (except basic rocks), as well as on old alluvium with sandy or loamy texture. They are found on many different types of topography, from flat to rolling, though most are found in hilly areas.

/Also

64

Also covered by this unit are soils of the more or less wide valleys of the hilly areas as well as the soils of plateaus with undulating to rolling topography.

On satellite pictures, no criteria seem to differentiate these soils from those of units 16 and 24.

Laying on such different bedrocks, these soils have varying morphologic characteristics. The typical profile is given by F.R. Moorman: under a humiferous upper horizon, of a grayish-brown colour, is a yellowish-brown leached area. The two upper horizons are clearly lacking in fine elements and have a loamy sand texture. The underlaying accumulation horizon has a clayey texture of red to yellow colour, and a clearly polyhedric structure. Many variations are found on this typical profile. The depth may vary from less than a meter to several meters according to the slope and the nature of the bedrock. Some profiles can be very stony.

Ferruginous concretions are often found in the profiles. The pH stays around 4.5. The base saturation and water retention capacity are low. These soils dry deeply during the dry season and are very susceptible to erosion.

Associations: ferralic cambisols and dystric nitosols.

Inclusions: ferric acrisols and lithosols.

4.20 Ferric acrisols, petric phase

Ferric acrisols are well developed on old loamy to clayey alluvium of the middle terraces in northeast of Thailand. They also occur in Lao PDR over wide areas. The topography of these areas is in general flat to slightly undulating. In these low lying regions, open forests and the absence of crops resulting from a very low fertility of the soil are characteristics which can easily be identified on satellite pictures.

/These

These soils are characterized by a hard laterite layer or by a large proportion of laterite concretions near the surface or at a shallow depth. The sandy to loamy upper horizon is very gravelly but often erosion uncovers the hardened horizon. Their real depth normally varies between 10 and 50 cm. These soils are acidic.

4.21 Ferric acrisols associated with plinthic acrisols

In Viet-Nam and Kampuchea, these soils occupy old sandy and sandy-clay alluvial terraces of the Mekong as well as the plains around the Great Lake. They are also found in valleys, on slope colluvium material and on sandy material resulting from weathered acid rocks. In such cases they are often associated with lithosols. The topography of these areas is usually flat with occasional more undulating areas.

On satellite pictures, these soils cannot usually be differentiated from the previous unit since they too are poor and mostly uncultivable. The vegetational cover is mainly composed of dry dipterocarp forest.

Ferric acrisols have a sandy to clayey upper horizon, grayish-brown in colour with a generally very low humus content. A feebly-developed B horizon is a yellowish-brown to light greyish-brown colour with large reddish spots. These soils contain hardened ferruginous concretions with a higher clay content. The water retention capacity is low, and most of the ferric acrisols are extremely dry and hard during the dry season. They are acidic and their exchange capacity and base saturation are very low. They are highly erodable.

Plinthic acrisols associated with these soils are found in particular in the eastern region of Kampuchea and in the part of Viet-Nam where precipitation amounts to more than 2,000 mm per year and where the dry season is short. In all other regions with marked dry seasons, plinthites can occur at a great depth in which case they are not involved in our classification. In some regions of western Kampuchea,

/these

these soils contain large proportions of ferruginous concretions or have hardened laterite horizon at a shallow depth. In fact, these constitute a lateritic phase of ferric acrisols. These soils, which are poor and often too dry for agriculture, erode very quickly on the slopes of deep valleys.

Inclusions: gleyic and orthic acrisols, ferralic cambisols.

4.22 Gleyic acrisols associated with dystric planosols

These are almost exclusively found in lower and almost flat areas of various formations. They are normally found on old alluvium, sometimes on semi-recent affluvium and on colluvial material of acid rocks. They are typical of depressions on low alluviul terraces, and of areas where the water table level stays close to the surface practically throughout the year. Somewhat poorly to poorly drained, they are water-logged and often flooded during the rainy season but dry out deeply in the dry season.

These soils can easily be identified on satellite pictures. During the rainy season, flooding and waterlogging, which are typical of this unit, give grey shades which become darker as these phenomena become more important. During the dry season, on the contrary, grey shades become very light. This high radiance is due to the drying of the soils and to an extensive occupation by harvested rice fields at this time of the year.

The surface horizon of gleyic acrisols varies from loam to sandy-loam. It lays on a loamy to clayey textural B horizon well or poorly developed, with the clay content increasing generally and progressively with depth. The colour varies from light grey to light greyish-brown with many spots throughout the profile. The structure is very poorly developed or massive, especially at the surface. Most of these soils easily become compacted when wet, practically sealing

/the surface..

the surface after a strong rain. This natural phenomenon may also be due to the puddling of rice fields. Many gleyic acrisols develop a compact plough pan immediately under the plough horizon. The organic matter content is generally low when these soils are not covered by forests. They are acid, and their exchange capacity and base saturation are low. They show important variations which are related to the age of the sediments on which they have developed.

Dystric planosols are in particular found in various parts of Kampuchea. Similar to the previous types of soils, they are however characterized by a sudden change in texture between horizons A and B or by a very compact and impermeable underlaying horizon. Inclusions are composed of gleyic solonetz, ferric acrisols and dystric gleysols. Dystric gleysols correspond to acid alluvial soils with a well developed B horizon and a low base saturation rate. Gleyic solonetz have a compact B horizon and a very high percentage of exchangeable sodium.

4.23 <u>Gleyic acrisols associated with ferralic cambisols and ferric acrisols</u>

This association is specific to the northeast provinces of Thailand with a mainly undulating topography. The gleyic acrisols (unit 22) are found in lower areas, with the ferralic cambisols (unit 16) and ferric acrisols (unit 20) in higher parts.

The relative importance of the various components varies according to area and topography. In flat areas, gleyic acrisols predominate over other associated soils while in areas with a more accentuated topography, the opposite is noted. Often, each of the elements of this unit is visible on satellite pictures, but the elements cannot be mapped separately since their respective areas are much too small.

/4.24

4.24 Dystric nitosols associated with chromic cambisols

These soils are found on residuum and colluvium resulting from the weathering of intermediate or basic rocks. The topography varies from undulating to rolling with occasional more accentuated features due to the presence of mainly limestone rocky outcrops which create important escarpments. The topography may in some cases be considered as a peneplain with a soil cover resulting or influenced by basic rocks.

There are few criteria to immediately distinguish these soils on satellite pictures. They are in general covered by a dense and mainly evergreen forest deeply degraded by crops, though this criterion is not specific to these soils. When the bedrock is different from the basic rocks mentioned on geological maps, these soils cannot be differentiated from unit 19 in the valleys of hilly areas.

Dystric nitosols are in general very deep, brittle, and of a red to reddish-brown colour. They have a clayey-loam to clayey A horizon and a clayey textural B horizon, though the horizon separation is not clear. In the B horizon, aggregates have a clayey revetment and the clay content increases with depth. These soils have a moderate acidity and their rate of base saturation is below 50%. The exchange capacity is moderate. The organic matter content is to a large extent related to the vegetational cover. They have good physical properties such as brittleness and a high water retention capacity.

In some regions, dystric nitrosols which have developed on limestones, are associated with brittle and moderately deep chromic cambisols of a reddish-brown colour and without a textural B horizon.

Inclusions: vertisols, rendzines and some lithosols.

4.25 Orthic ferralsols

These occur often on alluvial terraces of northeast Thailand which, located higher and well above surrounding and more recent terraces, are considered as the oldest. The topography is rolling with steep slopes here and there.

/This

This unit can be rather precisely distinguished through a comparative study of topographic and pedologic maps and satellite pictures. It is often apparent on satellite pictures because of the presence of dry dipterocarp forests or intensively cultivated areas.

Orthic ferralsols are deep, well drained, and red to yellowish-red. Horizon A, with a generally sandy to loamy texture, often shows signs of degradation: fine particles migrate towards the base bringing about the formation of an A_1-A_2 sequence in the B horizon, and the texture becomes clayey-sandy-loam.

Separations between horizons are progressive except for the lower limit of the upper horizon which is very shallow and of a somewhat darker colour. The structure is poorly developed. Brittle when wet, these soils become very hard when they are dry. Their pH varies from very acid to moderately acid. The base saturation rate is variable and the exchange capacity is very low. The organic matter content is related to the vegetational cover but is generally low as is the water retention capacity.

4.26 Rhodic ferralsols

Rhodic ferralsols are found mainly on plateaus of volcanic origin in Kampuchea where they constitute the "red lands". These basaltic formations have an undulating to rolling topography.

Most of the rubber plantation are located on these formations. Clearly apparent on satellite pictures, they give good indications for mapping.

Rhodic ferralsols which have developed on clay resulting from an alteration of basalt are deep and brittle. Under a more or less humiferous loamy-clay to clayey upper layer appears a dark reddish-brown clay which extends in general without obvious changes over a considerable depth (more than 50 m.). The organic matter content, which varies from

/low

low to moderate, is related to the vegetational cover and to the slope. These soils are moderately acid and have a low exchange capacity. They are well drained, porous, and have a good water retention capacity. The clotty structure of the upper horizons, which facilitates a very easy infiltration of rain water, preserves these soils from erosion.

Inclusions: orthic ferralsols, some vertisols and some lithosols.

4.27 Rhodic ferralsols associated with orthic ferralsols

These occur on basalt plateaus with a normally rolling topography. These plateaus are often deeply cut by erosion which gives the topography a very typical aspect of more or less narrow table lands with ridges surrounded by deep erosion valleys.

These soils have a red to yellow-red colour. Profiles are deep with a clayey texture and a structure varying from clotty to slightly polyhedric. Ferruginous concretions may appear at various levels, sometimes close to the surface.

Inclusions:—some acric ferralsols and some lithosols.

4.28 Acric ferralsols associated with orthic ferralsols

This unit occupies the larger part of the Pleiku-Kon Tum basalt plateau. This deeply eroded surface shows a rolling topography with less eroded surfaces here and there.

Acric ferralsols compare with rhodic ferralsols in many characteristics. However, they have a very low fertility, confirmed by an extremely low exchange capacity. They have a very acid pH. Their base saturation is very low. Their water retention capacity is low and they dry very quickly in the dry season. These characteristics, along with their very high brittleness, turn them into thin dust during dry periods. They are well drained and porous.

/Orthic

Orthic ferralsols have redder or lighter colours and a higher exchange capacity.

Inclusions: some rhodic ferralsols and some rhodic acrisols.

4.29 Dystric histosols

These peat and muck soils occur in the western parts of the Mekong delta a few meters above sea level and are generally covered by swamp forest with <u>Melaleuca</u>; they are typical of more or less water-logged soils, where water renewal is slow, and have in general a large content of acids and organic matter.

The mapping of dystric histosols is based on the presence of swampy vegetation with <u>Melaleuca</u>, observed on satellite pictures.

They are characterized by a peaty layer of at least 40 cm, almost exclusively composed of organic matter and which can reach a depth of several meters. Some peats have a high sulphur content, becoming very acid when drained.

Access to this region being difficult, the pedological composition of the peaty-soils is not known.

V. Surface hydrology

In view of the extent of the lower Mekong basin, is was not possible to represent floods and water subsidence as a coherent whole. Because of the extensive cloud cover, rainy season satellite data are insufficient. We could only plot the approximative maximum limit of areas which in 1972 - 1973 were covered by a layer of water or were very humid.

/No

No distinction has been made between floods proper(resulting from overflowing rivers and streams), rain water generally accumulated in rice fields during the rainy season, and waterlogged or very humid soils. The delineation of these wet areas involves a very large part of subjective appreciation.

Results obtained are represented at a very reduced scale because of their limited usefulness and their lack of precision.

This study is essentially based on the interpretation of band 7 composite colour transparencies and black and white transparencies taken during the rainy season (LANDSAT I).

VI. Comparative table of soil units

Lower Mekong basin	THAILAND	VIET-NAM	KAMPUCHEA
1 Alluvial soils, undifferentiated		1 Alluvial soils, undifferentiated 3 Acid alluvial soils 4 Very acid alluvial soils	
2 Eutric fluvisols		5 Brown alluvial soils of the river levees	14 Brown alluvial soils of the river levees
3 Eutric fluvisols (saline phase), eutric gleysols		1 Alluvial soils, undifferentiated	
4 Thionic fluvisols		4 Very acid alluvial soils	
5 Thionic fluvisols humic gleysols		3 Acid alluvial soils	9 "alune" soils (cat clays)
6 Eutric gleysols	2 Alluvial soils on recent fresh water alluvium	1 Alluvial soils, undifferentiated	13 Alluvial soils 15 Lacustrine deposits
7 Eutric gleysols, mollic gleysols		1 Alluvial soils, undifferentiated	13 Alluvial soils
8 Mollic gleysols		1 Alluvial soils, undifferentiated	
9 Humic gleysols, Dystric gleysols ("cuirasse" phase)			7 Hydromorphic soils of lateritic origin
10 Lithosols, Haplic phaeozems	22 and 23. Undifferentiated steep land or shallow red brown earths on limestone crags or lava plateaus and volcanos	8 Shallow regurs and latosols (generally shallow) on basalt	12 Basic lithosols
11 Luvic arenosols		11 Sandy podzolic soils on acid rocks	
12 Rendzines, Pellic vertisols Calcaric cambisols			10 Regur (on calcic bedrock)

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Lower Mekong basin	THAILAND	VIET-NAM	KAMPUCHEA
13 Pellic vertisol, Chromic vertisols	10 Grumosols		10 Regur (on basaltic bed-rock)
14 Gleyic solonchaks, Thionic fluvisols Eutric fluvisols		2 Saline alluvial soils	16 Coastal complex
15 Gleyic cambisols, Gleyic luvisols		6 Regosols on white and yellow dune sand	
16 Ferralic cambisols, Ferric acrisols	14 Grey podzolic soils		1 Red-yellow podzolic
17 Gleyic luvisols, Orthic luvisols Eutric gleysols	7 Low Humic Gley		8 Brown hydromorphic soils
18 Orthic acrisols	20 and 21 Shallow red-yellow podzolic soils and reddish-brown lateritic soils on steep land	18 Complex of montainous soils, mostly red and yellow podzolic soils and lithosolic soils	11 Acid lithosols
19 Orthic acrisols, Dystric nitosols, Ferralic cambisols	15-16-16p Red - yellow podzolic soils	12 Red and yellow podzolic soils on acid rocks 13 Red and yellow podzolic soils on old alluvial sediments	
20 Ferric acrisols, Petric phase	15L. Red - yellow podzolic soils with lateritic gravel		
21 Ferric acrisols, Plinthic acrisols		14 Grey podzolic soils on old alluvial sediments	4 Lateritic clays
22 Gleyic acrisols, Dystric planosols	7 Low humic gley soils	15 Low humic gley soils on old alluvial sediments	5 Cultivated hydromorphores soils 6 Grey hydromorphic soils 3 Planosols
23 Gleyic acrisols, Ferralic cambisols, Ferric acrisols	9 Low humic gley soils and red-yellow podzolic soils with laterite		

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Lower Mekong basin	THAILAND	VIET-NAM	KAMPUCHEA
24 Dystric nitosols, Chromic cambisols	17 Reddish-brown lateritic soils 13 Red brown earth		2 Latosols (Western)
25 Orthic ferralsols	19 Red and yellow latosols		
26 Rhodic ferralsols	19 Red and yellow latosols	19 Reddish-brown latosols on basalt	2 Latosols (Eastern)
27 Rhodic ferralsols, Orthic ferralsols		20 Red and yellow latosols on basalt 23 Reddish-brown latosols and red latosols on basalt	2 Latosols (South-Eastern)
28 Acric ferralsols, Orthic ferralsols		21 Earthy red latosols on basalt	
29 Dystric histosols		25 Peat and muck soils	

Note:

Figures correspond to the numbers given to the units used in the various soil maps.

C. LAND CAPABILITY MAP

I. Definitions

Soils described in the pedo-geomorphologic map are grouped in this section according to their capability for rice cultivation and rain-fed crops. Their classification is based on the simplified method presented in the "Soil Survey Interpretation Handbook for Northeast Thailand, Part II", Soil Survey Report No. 60, 1967, by D.L. Gallup, Srilak Kashemsanta, and Avudh Pimpand.

- Capital U corresponds to land classes suited for rain-fed crops.

- Capital P corresponds to land classes suited for rice (aquatic) cultivation. Rain-fed rice cultivation (i.e. without bunds) comes under rain-fed crops.

1.1 Rain-fed crops

Class U-I - Soils very well suited for rain-fed upland crops. No limitation.

Class U-II - Soils well suited for rain-fed (upland) crops. Few limitations.

Class U-III - Soils fairly well suited for rain-fed (upland) crops. Limitations: moderate.

Class U-IV - Soils poorly suited for rain-fed (upland) crops. Serious limitations restricting the choice of crops and/or reqairing special cropping techniques or conservation practices.

1.2 Rice cultivation

Class PI - Soils very well suited for paddy land. No limitation.

Class PII - Soils well suited for paddy land. Slight limitations.

/Class PIII

Class PIII - Soils fairly well suited for paddy land. Moderate limitations.

Class PIV - Soils poorly suited for paddy lands. Serious limitations restricting the choice of crops and/or requiring special cropping techniques or conservation practices.

II. Description of land capability units

Each of these units covers one or several of the soil described in the pedo-geomorphologic map and presents in practice equivalent agricultural capabilities.

2.1 Regions mainly suited for paddy cultivation

Unit I : very well suited for paddy land and moderately for rain-fed (upland) crops. Land capability classes: PI-UIII.

This unit corresponds to mollic gleysols (unit 8) and gleyic luvisols associated with orthic luvisols and eutric gleysols (unit 17). These fertile soils have as a whole no major limitations.

Unit II : well suited for paddy lands. Limitations result from flooding with salinity hazards in coastal areas. Land capability class: PII.

Are as covered by this unit:

- undifferentiated soils (unit 1), eutric fluvisols, saline phase, associated with eutric gleysols (unit 3). Highly fertile, these soils can become very productive when protected from flooding.

- Eutric gleysols (unit 6) and eutric gleysols associated with mollic gleysols (unit 7). Of a rather high fertility, these soils can be very well suited for paddy land if water control is provided.

Unit 3 : well suited for paddy land and moderately suited for rain-fed crops on better drained uplands. The major limitation

/results

results from drying of the soils. Land capability classes: PII-UIII.

This unit corresponds to pellic vertisols associated with chromic vertisols (unit 13).

Unit 4 : moderately suited for paddy land. The low water retention capacity, the low fertility or the high acidity of these soils are the main limiting factors. Land capability class: PIII.

This corresponds to:

- Thionic fluvisols associated with humic gleysols (unit 5). Their generally very high acidity may make them unsuited for agriculture. They are very badly drained.

- Gleyic acrisols associated with dystric planosols (unit 22). They have a low fertility and are poorly drained.

2.2 Zones mainly suited for rain-fed crops

Unit 5 : moderately suited for rain-fed crops. The low fertility of the soils and their flooding are the main limiting factors. Land capability class: UII.

This unit covers:

- Eutric fluvisols (unit 2), very fertile and particularly well suited for orchards.

- Dystric nitosols (unit 24) associated with chromic cambisols have a low fertility but very good physical properties. Their drying out during the dry season is one of the main limiting factors.

/Rhodic

Rhodic ferralsols (unit 26) have, as far as their chemistry is concerned, a rather low fertility but they give the best cultivable lands of the basin. This property results from their very good physical characteristics. They are particularly well suited for industrial crops.

Unit 6 : Well suited for rain-fed crops and moderately suited for rice cultivated on flat areas. Land capability classes: UII-PIII.

These are formed by rendzines associated with pellic vertisols and calcaric cambisols (unit 12). These soils have a high fertility but their shallowness and their strong desiccation during the dry season are limiting factors as far as agriculture is concerned.

Unit 7 : moderately suited for rain-fed crops. Their desiccation, low fertility, and easy erodability are the main limiting factors. Land capability class: UIII.

This unit covers:

- Gleyic cambisols associated with gleyic luvisols (unit 15), these have a limited agricultural value and are usually used for fruit cultivation and for a few food crops that have poor yields. However, most are uncultivated.

Ferralic cambisols, associated with ferric acrisols (unit 16), have a low fertility.

Orthic acrisols associated with dystric nitosols and ferralic cambisols (unit 19), also have a low fertility. Orthic acrisols are too sandy, too stony, or located on steep slopes, and are best used for pastures or forest reserves.

/Ferric

- Ferric acrisols, associated with plinthic acrisols (unit 21), are poor and often too dry. They erode very quickly on the slopes of some steep valleys. Most of these soils are uncultivated. The vegetational cover is mainly open dipterocarp forest.

- Orthic ferralsols (unit 25) have a low fertility. Characteristic steep slopes are one of the important limiting factors. They are well suited for fruit trees with deep roots.

- The agricultural potential of rhodic ferralsols associated with orthic ferralsols (unit 27) are limited by their very marked topography. Water and soil conservation are required to make these soils productive.

- Acric ferralsols, associated with orthic ferralsols (unit 28), have a very low fertility. Soil and water conservation is essential.

2.3 Zones suited for paddy lands and rain-fed crops

Unit 8 : Moderately suitable for paddy land and rain-fed crops. Land capability classes: PIII-UIII.

This unit corresponds to gleyic acrisols associated with ferralic cambisols and ferric acrisols (unit 23). The main limiting factor is their low fertility.

2.4 Zones poorly suited for crops

Unit 9 : poorly suited for rain-fed crops and paddy lands. Severe limitations. Land capability classes: PIV-UIV.

- The very high acidity and the poor drainage of thionic fluvisols (unit 4) and dystric histosols (unit 29) and the high salinity and poor drainage of gleyic solonchacks associated with thionic fluvisols and eutric fluvisols (unit 14), make these unsuited for cultivation.

- Humic gleysols associated with dystric gleysols, laterite phase (unit 9), have a low fertility, are poorly drained, and are shallow.

/Unit 10:

Unit 10 : poorly suited for rain-fed crops. Severe limitations. Land capability class: UIV.

- The shallowness and stoniness of litosols associated with haplic phaeozems (unit 10) are limiting factors for rain-fed crops.

- Luvic arenosols (unit 11), are too sandy, too dry, often too stony and of a very low fertility and are therefore not suited for agriculture.

- Orthic acrisols, associated with lithosols (unit 18), have a low fertility, are shallow, stony and located on a very marked topography, and are therefore poorly suited for crops.

- The presence of laterite on the surface of ferric acrisols, laterite phase (unit 20) is an important limiting factor.

III. Annex: Rice cultivation and rainfall

In practice, nearly all rice produced in the lower Mekong is grown during the rainy season. Rice cultivation, mainly rain-fed, depends on rainfall which may be relatively scarce, especially during the first part of the rainy season.

The volume of precipitation and its distribution over the rainy season varies considerably from one region to the other according to various factors such as the distance from the sea, the latitude, the elevation, the exposure to prevailing monsoon winds, etc.

In order to delineate regions best suited for rain-fed rice cultivation, an analysis of monthly precipitation data supplied by 141 rainfall stations was carried out for the months during which rice is cultivated; these data were compared with rice water requirements. It was assumed that local rice varieties require a minimum of 120 mm rainfall per month, with this criterion applying at least four years out of five.

/To delineate

To delineate areas where rain-fed rice cultivation is practicable the following factors were considered:

(a) Number of months during which precipitation is above 120 mm;

(b) Duration of periods of drought during the rainy season;

(c) Date of the beginning and the end of the rainy season;

(d) Macro-relief of the basin;

(e) Knowledge obtained through practical observation.

The map attached to the back cover of this report gives in a simplified version the results of this analysis. The basin is subdivided into four areas according to suitability for rain-fed rice cultivation : (I) unsuited, (II) marginal, (III) moderately suited and (IV) well suited.

Zone I

This zone of drought corresponds to a "rain shadow" area (east of the Petchabun, Elephant and Cardamomes ranges). Although considered as insufficient because of scarce precipitation at the beginning of the rainy season, rain-fed rice cultivation is widely practised in these areas through the ingenuity of the farmers. Thus, for instance, water collected in the highest plots is redistributed to lower plots where replanting begins.

Zone II

Cultivation is limited to lowlands where local seepages, added to rainfall, makes it possible to grow rice during the second half of the rainy season.

/Zone III

Zone III

This zone is relatively well suited for rain-fed rice cultivation especially in northeast Thailand where this type of cultivation, practiced for hundreds of years, is very quickly spreading to higher forest lands through simple levelling and construction of bunds which allow the accumulation of rain water. Yields are relatively low and the irregularity of precipitation makes it impossible to cultivate every year the entire area of potentially cultivable lands.

Zone IV

The volume of precipitation is sufficient to carry out rain-fed rice cultivation in the hilly regions of Laos and of the south Vietnamese Annamitic Cordillera as well as in most of the Mekong delta.

Note

This study was done Dr. Y. Kaida.

ADDITIONAL STUDIES

Additional studies proved essential for the completion of the thematic map programme.

These studies give a better understanding of the natural environment, thus facilitating the preparation of the proposed thematic maps. Moreover, they give a better understanding of units that have been retained and make it possible to map for the first time regions that are not yet properly known. These studies have mainly dealt with:

- sedimentation in the Mekong delta; and
- sedimentation in the Nam Mun and Nam Chi basin (north-east Thailand).

Entirely based on an interpretation of satellite images, these studies give an overall picture of the two largest morphologic units in the basin, corresponding to the Mekong delta and the Korat plateau.

Images studied correspond to bands 5, 6 and 7 of the multi-spectral scanner. In general band 4 images have not been used because of their lack of precision. Results were obtained from a systematic study of all pictures taken every 18 days (positive black and white transparencies at the scale of 1:1,000,000 and corresponding composite colour transparencies).

A. OUTLINE ON SEDIMENTATION IN THE MEKONG DELTA

I. Holocene delta

1.1 Very humid alluvial landscape

On either side of the delta are found two large areas which are waterlogged in all seasons and covered by swampy vegetation.

1.1.1 The Plain of Reeds: Located in the eastern part of the basin, it is in a depression which collects waters coming from the north which are prevented from draining in a southern direction by the SW/NE fault passing through Ho Chi Minh City and the Cay Lay/Tan An fossil shore line. Beyond are found soils of the coastal complex which are well drained and dry for longer periods. (On thematic maps, the Plain of Reeds generally occupies a larger area than the area we mapped. The landscape unit described here corresponds only to that part of the Plain which is permanently waterlogged and without old fluviatile patterns).

1.1.2 Chau-Phu-Hatien-Rach Gia delta

This western part of the delta is always waterlogged and uncultivable; it corresponds to an old delta, the fossil hydrographic network of which is still visible. The main arms, which are especially clear on 16/12/76 pictures because of their dark grey shade, start from the always-humid depression followed by the Stung Takeo. These however do not facilitate an efficient drainage of this area, apparently because of the existence of a barrier which runs between Chau Phu and the western rocky hills (3/1/73 pictures show this barrier as much drier during this season). The barrier is followed by the Kinh Vinh Te canal which should itself be an obstacle to the flow of water in a southernly direction.

In view of the extent of this swampy deltaic area, and of its ancient arms, it can be assumed that the Mekong followed this path in the Holocene period.

/1.2

1.2 Allavial landscapes with variable hamidity

These can be divided into three separate units. In view of the lack of data, we are making use of the following rather general terms: modern, semi-recent, and ancient.

1.2.1 Modern alluvial landscape (modern delta)

In the Mekong arms region, i.e. from Sadec to the coastal complex, 8/5/72 pictures show a mosaic of small light spots (dry soils) and dark spots (humid soils) as well as the generally parallel alignment of the river arms. These formations can be considered as fossil alluvial levees resulting from the successive shifting of the Mekong, their northern limit being the old Cai Lay-Tan An sea coast.

No similar landscape has been found in the Song Hau Giang region. It seems that the bed of this arm of the Mekong, which runs in a straight line over a long distance, has never shifted significantly. Only very few fossil river alignments, very close and parallel to the river, are apparent here and there.

It is probable, however, that the alluvial levee located halfway between the Song Hau Giang and the Song Co Chien corresponds to a former bed of the Song Hau Giang. The pattern of the shore lines shows that this bed was only used during a part of their formation. According to the pictures, it is the only sign of a fossil alluvial formation in the western part of the delta.

1.2.2 Semi-recent alluvial landscape (semi-recent delta)

In the eastern part of the delta between old Pleistocene alluviums of the Mekong and the modern delta, satellite pictures show a complex system of alluvial levees (which appear in light shades since they are better drained) and more humid areas (in darker shades). Their pattern corresponds to the old forms of an important hydrographic

/network

network, the layout of which is generally difficult to understand since it is related to soil humidity which varies widely in this region. A systematic study of all pictures is required.

This network of arms is partially linked with the Mekong near Hong Ngu. The area seems to correspond to a barrier which prevents an efficient drainage of Mekong backswamp areas into the Plain of Reeds depression. All that normally remains during the dry season is a narrow and wet gully linking the two depressions.

1/4/75 pictures show alignments which most probably correspond to ancient alluvial levees running more or less parallel to the Vam Co Tay. In view of their general orientation, the existence of an extensive hydrographic network originating in the Vam Co Tai watershed can be assumed.

1.2.3 Ancient alluvial landscape

In the western part of the delta (Chau Phu-Hong Ngu-Sadec-Can Tho-Rach Gia area) none of the patterns previously observed (except near the Song Hau Giang) can be seen. The landscape is however, characterized by a regular wet front which progressively withdraws in a southerly direction during the dry season. Thus the soils of the northern regions (Chau Phu-Sadec-Rach Gia) are dry during most of the year. The Mekong and the Bassac today flow on these alluviums.

In the Long Xuyen-Can Tho area, on both sides of the Song Hau Giang, an extensive area of permanent humidity is observed. It can apparently be related to tides and to the absence of alluvial levees.

1.3 Coastal complex

From the mouth of the Song Nha be to Rach Gia, satellite pictures show an extensive coastal complex.

/From

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From the south of Ho Chi Minh City and up to the Song My Tho, it is difficult to make out whether the pattern belongs to a system of shore lines or of alluvial levees. In view of the shape of ancient or recent shore lines observed further south it seems, however, that the divergent alignments of the river could be attributed to old shore lines. This assumption is confirmed by the fossil shore of Cai Lay-Tan An which has been studied and dated by H. Fontaine at 450 ± 110 years before the present.

Between the Vam Co Dong and the Song Nha Bé, the alignments take a west-east orientation. These correspond either to alluvial levees, slowly disappearing in the Plain of Reeds, or to the extension of some of the shore lines previously described with a change in orientation near the Vam Co Tay. West of Tan Han, the north-south alignments could apparently be related to a system of shore lines unconformable with the Cai Lay-Tan An shore line running further south, and disappearing as they reach the Plain of Reeds in the north.

During the dry season, this area is characterized by a deep drying of the soils which creates a sudden difference with the always wet Plain of Reeds area and relates it to the dry soils of the coastal complex appearing further south.

Beyond and up to Vinh Long, the form of the ancient and recent shores are especially clear. On ridges sheltered from floods are generally concentrated human settlements and road networks. Their pattern as a whole follows that of the present coast. Graphic unconformabilities which can be seen, show a regular progression of the delta towards the sea. (The shore line that is located furthest toward the sea stops the previous one). These also show that the various modern arms of the Mekong seem to have operated without major changes during the whole period of formation of the coastal complex visible on satellite pictures. Between shore lines often occur major and always wet depressions. Close to the mouths, some of these, are regularly flooded during the high tides.

/In the

In the western part of the delta, the shore patterns are more difficult to distinguish. Inland, these are no more represented by isolated patterns, and some appear on only a few pictures. Moreover, south of a line approximately running from Rach Gia to Cantho and Vinh Loi, the soils show generally a much more important humidity which may have various causes: sedimentation and tides varying on western and south-eastern coasts (amplitude 1 m in the west and 4 m at the mouths of the Mekong); subsidence, and others.

The extent of marine formations is certainly much more important than shown by the satellites. Mr. Fontaine mentions foraminiferous clays at a depth of 7 m at My Phuoc (south of Cantho).

II. River landscape upstream from the Holocene delta

Up to the Vietnamese border, the Mekong and the Bassac flow in an alluvial plain which is waterlogged and formed by backswamps running along these two rivers. On all pictures, these correspond to very dark shades evidencing a permanent and very important humidity. This landscape unit is moreover characterized by river bank levees, the importance of which could appear as abnormal. A study of 16/12/72 pictures shows that the lighter shades, corresponding to these levees, are located on both sides of a large number of small filling-up (colmatage) channels originating in the river. These result from a sedimentation of clayey materials suspended in the waters of the Mekong when these mix with very acid waters of the river backswamps. As a whole, these sediments give an important but artificial aspect to the alluvial levees of the Mekong and the Bassac.

III. Pleistocene period

3.1 Alluvial terraces

In its northern part, the Holocene delta is limited by formations belonging to an old alluvial plain of the Mekong (old terrace) which probably developed during the Pleistocene period. On dry season pictures,

/this is

this is shown by very light shades (resulting from a very extensive occupation of the soil by rice fields and from the low humidity of the soils) which create a contrast with the generally darker shades of more humid formations considered as belonging to the Holocene period.

Two levels can be distinguished:

- A low terrace, characterized during the dry season by complex and humid patterns of meanders corresponding to a fossil hydrographic network (more or less active in some parts of the region and during certain periods of the rainy season) which has a generally north-south orientation. Considering the extent of some of these patterns, it could be assumed that these are part of a major hydrographic network. They are also characterized by intensive flooding during the rainy season (10/11/72 pictures are particularly informative).

- A high terrace, located in the western part of the country and limited by a line running approximately from Phnom Penh to Kompong Trach. It differs from the previous unit by deeply anastomosed overland runoff lines generally oriented in a west-east direction and by minor floodings. This terrace may eventually appear also in the north and the east but satellite pictures do not make it possible to confirm this assumption.

3.2 Alluvial plains of the Ho Chi Minh City region

In the Ho Chi Minh City region, 1/4/75 pictures show valleys with very dark shades and therefore very humid, running in a straight line over long distances. These correspond to the Vam Co Dong and the Saigon flood plains through which runs a system of canals corresponding to a system of NNW-SSE faults.

/In addition

In addition to their privileged orientation, these are characterized, at least in their downstream part, by their great width which does not seem to be in proportion with the importance of today's rivers. A marine influence in their genesis is not impossible.

IV. Morphologic alignments

In addition to the already known alignments, satellite pictures, by their repetition, show alignments which only appear at certain specific periods through the conjunction of various hydrologic and biovegetal conditions.

4.1 Son Hau Giang alignment

Generally oriented in a NW-SE direction, this alignment extends in the north-west with the Stung Takev, practically limiting to the south-west the very humid depression followed by this river (3/1/73 picture). Further, one finds that extending this line will lead to the straight line upper course of the Stung Cheang. According to Manguy (1968), this would correspond to the axis of a high Korat-Kchol-Con Son region. This axis seems to play an important role in the sedimentation of the Song Hau Giang. It would sufficiently channel the course of this river to prevent it from shifting its bed (with the exception of the fossil arm mentioned on the left bank). It seems that a movement of this axis, with a collapse in eastern regions, might have caused the short circuiting of the Chau Phu-Hatien-Rach Gia delta.

4.2 Phnom Penh alignment

The Bassac is channelled by a NNW-SSE alignment which runs slightly west of the capital city. It corresponds to a fault already mentioned by various authors.

/4.3

4.3 Vam Co Dong and Saigon alignment

In the eastern part of the delta, satellite pictures show a series of NW-SE alignments which run parallel to each other and are followed by the present hydrographic network. In Kampuchea, flooding, which is seen to take place in Pleistocene formations, is stopped in the east by these alignments. In Viet-Nam, the western compartment is always more humid.

These alignments are considered by the author as faults affecting the western regions.

4.4 Ho Chi Minh City-Sadec alignment

Running in a SW-NE direction, this alignment appears clearly on LANDSAT I pictures of 2/1/73 and LANDSAT II pictures of 1/4/75.

At its eastern end, this alignment links Pleistocene and well drained alluvium that appear on the surface in the north with recent and very humid alluvial deposits of the south. In the west, it constitutes the northern limit of the humid Plain of Reeds depression, linking it with better drained marine and river deposits. Beyond, it is much more difficult to follow. It does not seem to have any influence on alluvial deposits of the modern delta, but an important elbow of the Mekong appears in its extension (north of Vinh Long).

This alignment can be assimilated to a fault which brought about a collapse of the northern part, thus preventing the drainage of the Plain of Reeds where disappear littoral and fluvial formations.

4.5 Hong Ngu alignment

North from Hong Ngu, 1●/11/72 satellite pictures show a NW-SE alignment, which, if it corresponds to a structural direction, could have played a role in the formation of the semi-recent delta, to the extent it

/isolated

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isolated the fossil hydrographic network originating in this area from the Mekong.

V. Present sedimentation of the Mekong

An outline of the present sedimentation of the Mekong is possible through an interpretation of satellite data.

The use of multispectral colour transparencies is particularly useful in this field. Sediment carrying waters give bluish shades while clear waters are black. These differences make it possible to study the movement of sediment-laden waters.

Study of the 10 November 1972 flood in the Phnom Penh region

Floods observed in the low Pleistocene terrace on the right bank of the Mekong do not seem to originate from the river proper but from tributaries and lateral runoffs. From Phnom Penh to the Stung Takev, these waters partially flow into backswamps located on the right bank of the Bassac. In the south, they flow into the Chau Phu-Rach Gia-Hatien depression after going between the granitic hills which are found in this region.

The Bassac waters stay clear even after mingling with the muddy Mekong waters near Phnom Penh. They do not take up sediment until they reach Viet-Nam, when they flow into an arm of the river (Vam Kao), north of Long Xuyen.

In the same manner, on the left bank floods are limited to the Pleistocene alluvial terraces. They are particularly extensive in the plains of the Vam Co Tay watershed. During high waters, this basin seems to communicate with the Mekong through a natural channel located between the basaltic range of Peam Cheang and Khun Russei Sunh. An evaluation of the inputs of the Mekong waters in this inundation plain subjected to high rainfall is difficult. The largest part of the floodwater is drained

/in

in a south-easterly direction and up to the Plain of Reeds by the Vai Co Tay and its tributaries.

A part of the sediment-laden waters of the Mekong follow the Tonle Toch. Alluvium is then deposited in the backswamps of the Mekong in the Prey Veng region.

During the November flood, therefore, there seemed to be no important alluvial inputs directly originating from the Mekong and the Bassac, in the backswamp depressions of these two rivers.

On 16/12/72, floods no longer appear on the terraces which, however, remain waterlogged. Traces of alluvium seen in backswamps appear once again without significant modifications.

Floods in the Holocene delta

During the month of November, muddy waters do not leave the bed of the Mekong up to its mouths where sea currents carry alluvium thrown into the sea in a south-westerly direction.

However, 22/10/72 pictures show a turbidity corona in the Sadec-Vinh Long area and 6/8/73 pictures show, near the mouths of the Mekong, a large input of sedimented water in depressions located between shore lines.

It therefore seems that during the month of November (end of the rainy season), most of the Mekong alluvium is directly taken from the Tonle Toch fork to the sea. A full and in-depth study of floods of the river would require a complete and cloudless time series of satellite pictures. Moreover, the 18-day interval between each picture seems to be far too long for a precise consideration of the evolution of Mekong floods.

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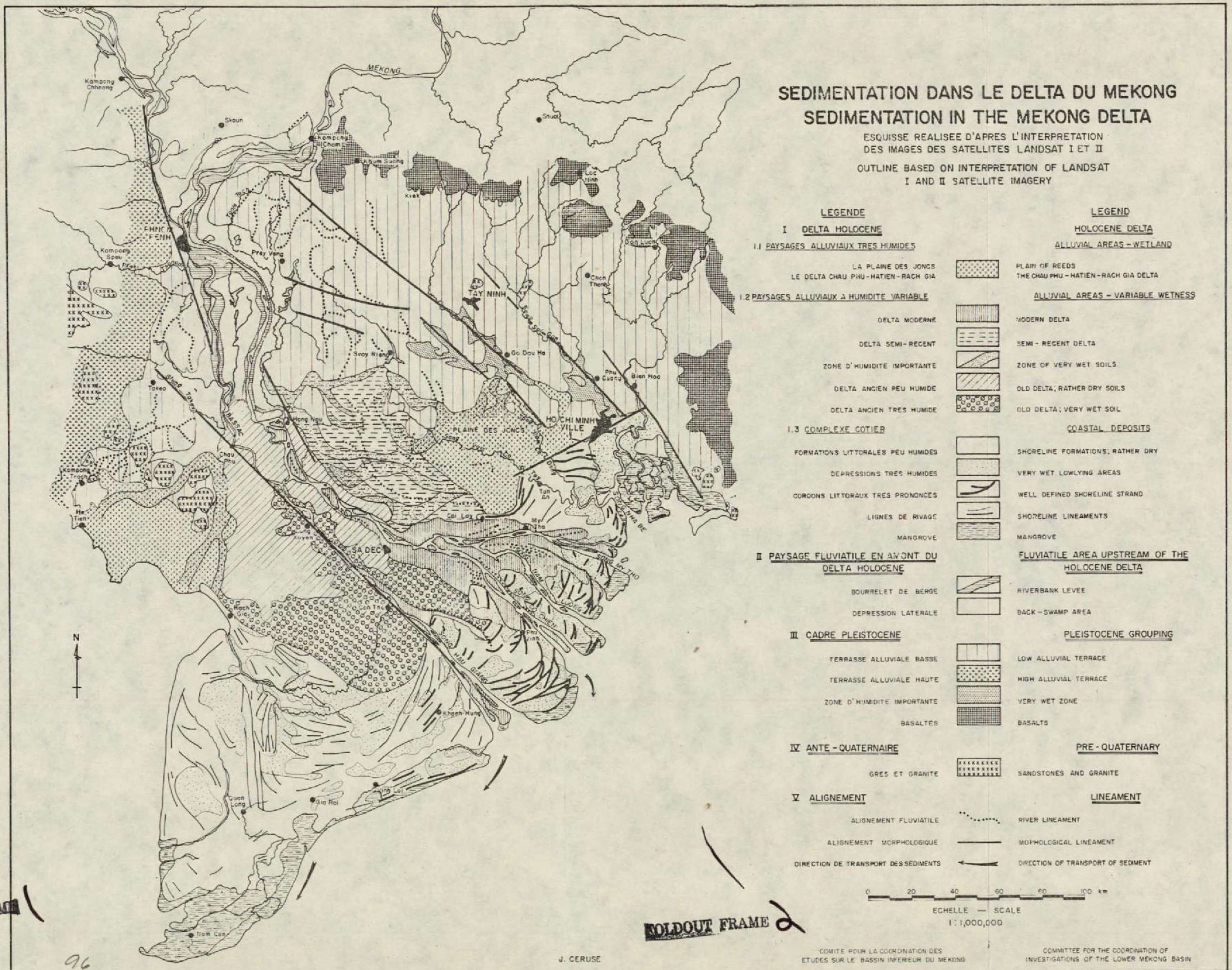

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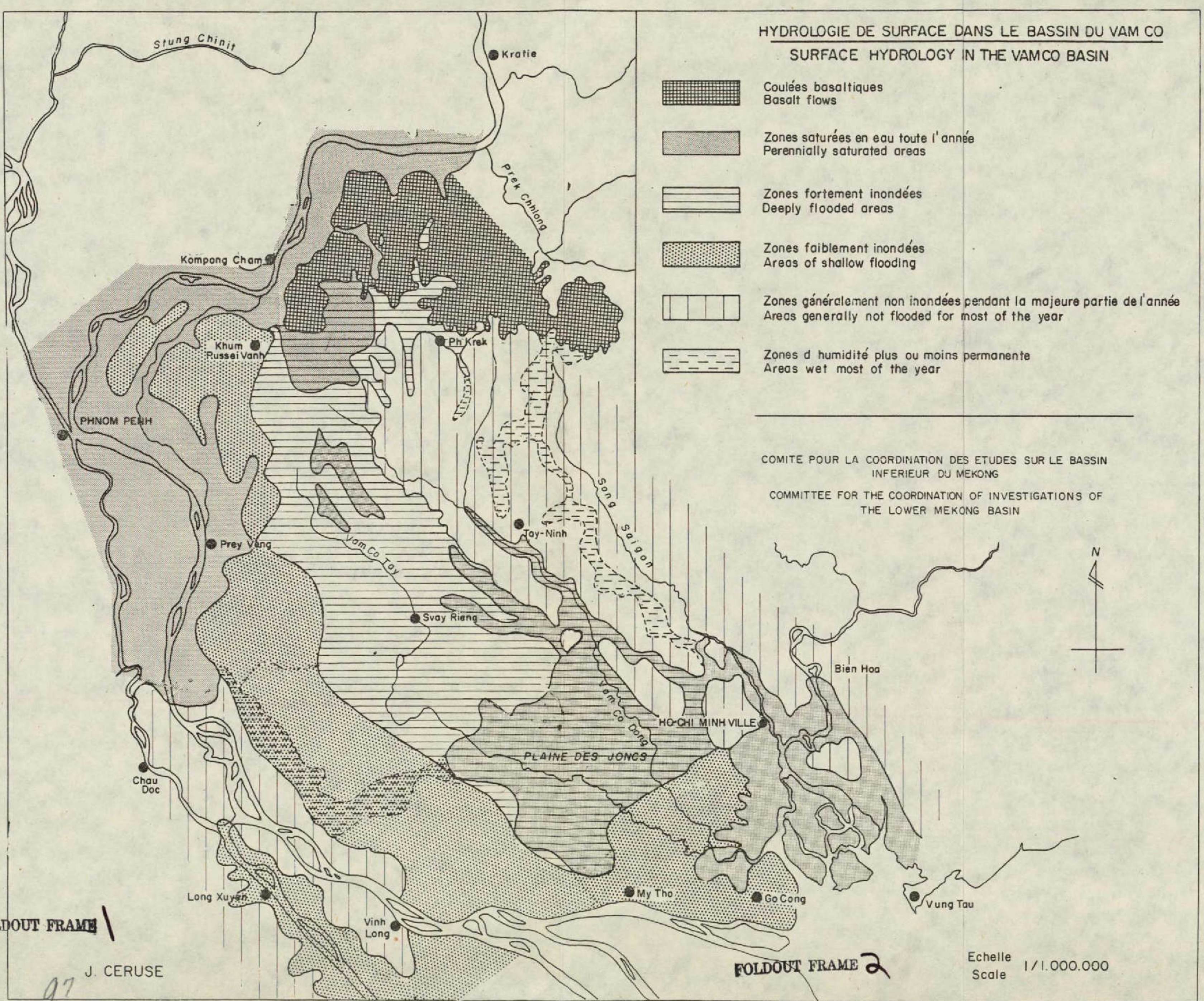

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VI. Surface hydrology in the Vam Co Tay watershed

Pictures from the end of the rainy season show a zone of preferential flooding (or more significant and persistent humidity) extending north-easterly from the always waterlogged Plain of Reeds. This zone bends in a northerly direction close to Prey Veng and ends against the basalt ranges of the Khum Suong-Krek area, beyond which are found the flood zones of the Mekong. In the west, the regions constituting the limits of the Vam Co Tay and Mekong watersheds can be flooded or very humid during the peak of the floods.

During the dry season, the Vam Co Tay plains are characterized by areas of high permanent humidity running in a NW-SE direction and certainly due to an important fossil hydrographic network.

It would seem that the Vam Co Tay watershed can be linked to an old Mekong valley interrupted by the occurence of basalt flows (which, according to J.P. Carbonnel, would have appeared some 650,000 years ago).

We think that the Mekong tends preferably to link with the Vam Co Tay basin in the region located between Kompong Cham and Khun Russei Sanh.

The Vam Co Tay watershed and the Plain of Reeds, through their hydrologic relations with the Mekong and their recent hydrologic history, are closely linked with the lower Mekong basin.

B. OUTLINE OF SEDIMENTATION IN THE NAM MUN AND NAM CHI BASIN (NORTH EASTERN PROVINCES OF THAILAND)

This outline is primarily based on an interpretation of satellite pictures, but also includes ground observations and the study of aerial photographs.

The Nam Mun and Nam Chi rivers flow through the southern half of one of the main morphologic units of Thailand, known as the "Korat plateau". The study of satellite pictures shows that the basin of these two rivers can be subdivided into several units.

I. Pre-Quaternary landscape

This corresponds to outcropping formations belonging to the Mesozoic era (sandstones, marls, and conglomerates...) and concretized by the sometimes imposing topography of the Phu Phan and Dangrek ranges. Shaped as a synclinal depression, it is progressively covered towards its center by the Quaternary alluvium of the Nam Mun and the Nam Chi. Where it has not been washed off by erosion, a mainly sandy layer of a generally light beige colour sometimes covers the sandstones and marls.

Sandstones are crossed by an intensive network of faults or joints, often channelling the hydrographic network. It seems that the system of cracks and alternating sandstones and marls determines the fish-bone shape of the hydrographic network observed in many places.

In relatively flat areas (undulating to gently undulating), it is sometimes difficult, on satellite pictures, to differentiate pedologic formations covering the substratum and fluviatile sediments. The typical pattern of the hydrographic network is the best criterion for differentiation.

/II.

II. Upper fluviatile terrace

This terrace, which has the highest elevation, is located upstream from the basin at an average elevation of 220 meters. Its elevation decreases slowly in a downstream direction to reach an altitude of about 160 m (in areas where we could study it). There are many indications of these river deposits. Those we could see form a practically continuous strip of eroded outliers found mainly on the left bank of the Nam Chi and the right bank of the Nam Mun.

The main characteristics appearing most of the time are:

- highly rubefied sands;
- important loose lenses of pebbles with abundant quantities of petrified wood, some reaching the dimension of a tree trunk. Two types of trees can be distinguished: trees apparently subcontemporary to river sediments and better petrified and less voluminous trees belonging to the Mesozoic era and resulting from the degradation of the Mesozoic limestone series;
- a lateritic layer where pebbles are sometimes cemented, showing evidence of a prolonged exudation of the nappe.

We believe that these sediments constituted a continuous fluviatile nappe covering the basin of the Nam Mun and the Nam Chi except for pre-Quaternary sandstone reliefs with higher elevation than this terrace, such as the Ban Phai, Borabu, and Roi Et upthrusting. Traces of these old river formations are visible even now between the two rivers. In addition to elevation, studies are also be based on 1:100,000 pedologic maps since the red-yellow latosols are generally formed on this type of alluvium.

/According

According to J.C. Carbonnel, these fluviatile deposits correspond to the terrace + 20 m of the series of fluviatile terraces found all over southern Indochina. According to this author, their formation has certainly taken place during the mid-Pleistocene or even upper Pleistocene era.

III. Lower fluviatile terraces

Satellite pictures show fluviatile sediments which stand as intermediaries between flood plains and upper terraces.

These very flat and often hardened (lateritic) formations are generally covered by dry dipterocarp forests. They are also characterized by sometimes very wide alluvial and often fossil valleys. Their importance is not related to the present hydrographic network, since they correspond to a former period of intensive alluviation. It would seem therefore that there is a system of low terraces which could be incorporated to the low terraces + 10 m in the time series proposed by J.C. Carbonnel.

IV. Flood plain

The Nam Mun and Nam Chi flood plains are easily identifiable on satellite pictures. They are characterized by the very light shades of the Nam Chi river (very well drained lands intensively occupied by rice fields) and by the darker shades of the Nam Mun (poorly drained land, always wet).

Extensive flooding of the Nam Mun valley is partially controlled by the dams built in the Nam Chi valley.

V. Depression landscape

The area extending approximately from Kaset Wisai in the west to Ubon Ratchathani in the east and limited by the Nam Mun in the south is characterized by:

/many

- many fossil and meander-shaped patterns; and
- many islets covered by an evergreen type of vegetation, food crops, orchards and human settlements.

This region corresponds to the lowest part of the synclinal depression of the Korat plateau, towards which flows the present hydrographic network. It is an area of natural sedimentation for sediments carried by the rivers. Large meanders have developed in this peculiar geomorphologic landscape.

In the east, this depression is only drained by the lower part of the Nam Mun river which crosses the synclinal limb of Mesozoic sandstones through a narrow valley before ending in the Mekong.

The islets are composed of finer sandy loose and non-hardened material (results of a few observations which should be expanded in the future). These soils are suitable for a richer vegetation than the one found on fluviatile deposits of the previous alluvial and often lateritic terraces. Topographically located at a higher elevation than the surrounding landscape constituted by wide lowlands crossed by meanders, these formations could correspond to run bank levees dissected by the successive shifts of river beds.

River sediments which were deposited in this depression seem to be relatively recent if we take as a basis the absence of the hardened layer found on fluviatile terraces.

VI. Erosion surface

Outlying this complex of Quaternary fluviatile deposits, and before reaching the Phu Phan and Dangrek ranges, satellite pictures show a relatively flat landscape. From some of the characteristics (sandstone outcrops, pattern of the hydrographic network) it could be

/assumed

assumed that the pre-Quaternary substratum is quite close to the surface. In the absence of more precise data, these landscapes can be linked to an eroded and certainly laterized surface, resulting from the action of water flowing from neighbouring ranges.

VII. Conclusion

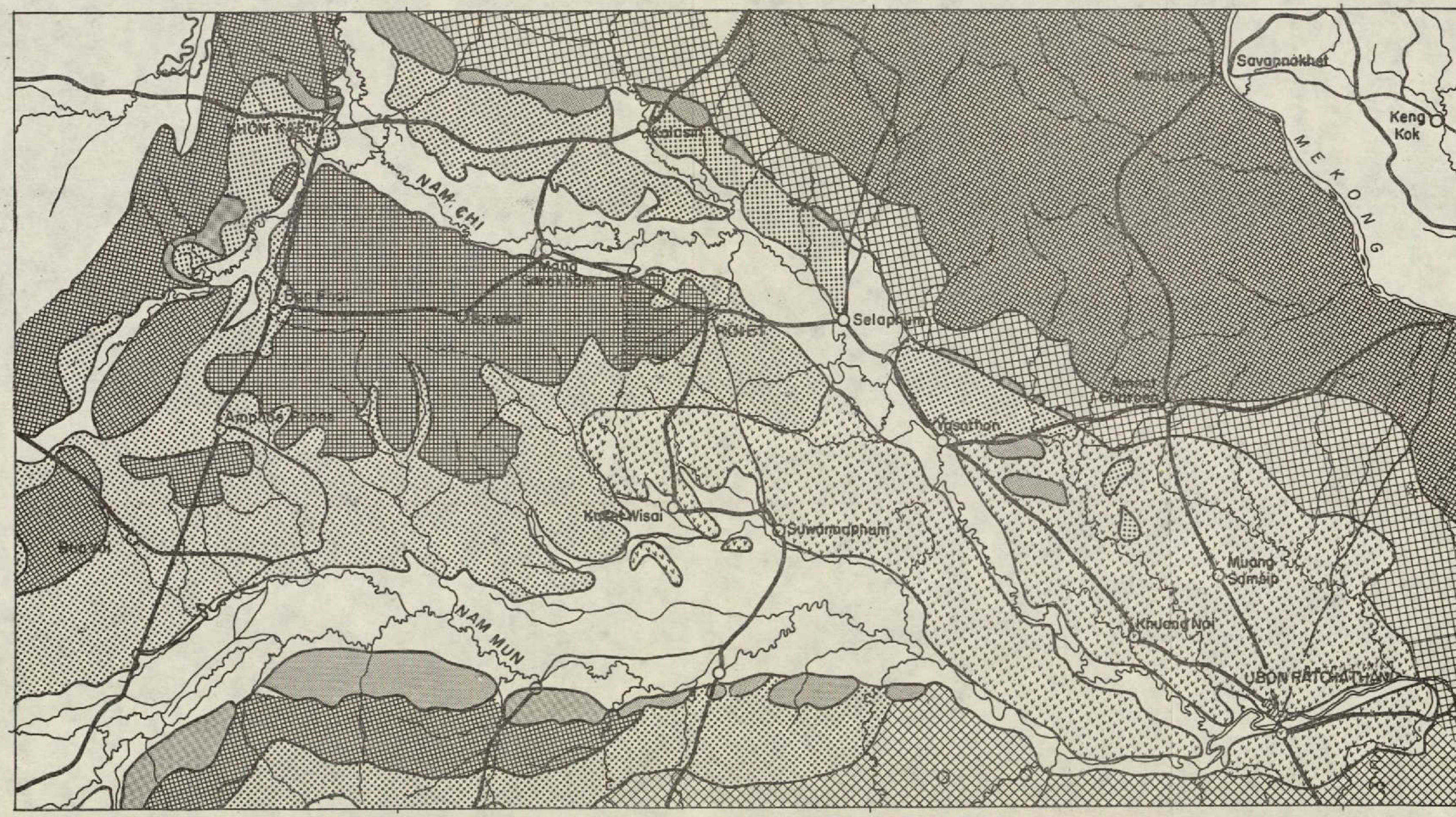
This study, which could serve as a basis for more advanced field work, is only a very brief outline of sedimentation in a part of the Korat plateau.

SEDIMENTATION DANS LE BASSIN DE LA NAM MUN ET DE LA NAM CHI
SEDIMENTATION IN THE NAM MUN AND NAM CHI BASIN

N

- Cadre - anté - quaternaire / Pre - quaternary
- Surface d'erosion / Erosion surface
- Terrasse fluviatile haute / High terrace (Fluviatile)
- Terrasse fluviatile basse / Low terrace (fluviatile)
- Plaine d'inondation / Flood plain
- Paysage de cuvette / Low basin landscape

Echelle / Scale 1 / 1.000.000



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ANNEX 3

REPORT ON
COMPUTER PROCESSING OF REMOTE SENSING DATA

Final Report

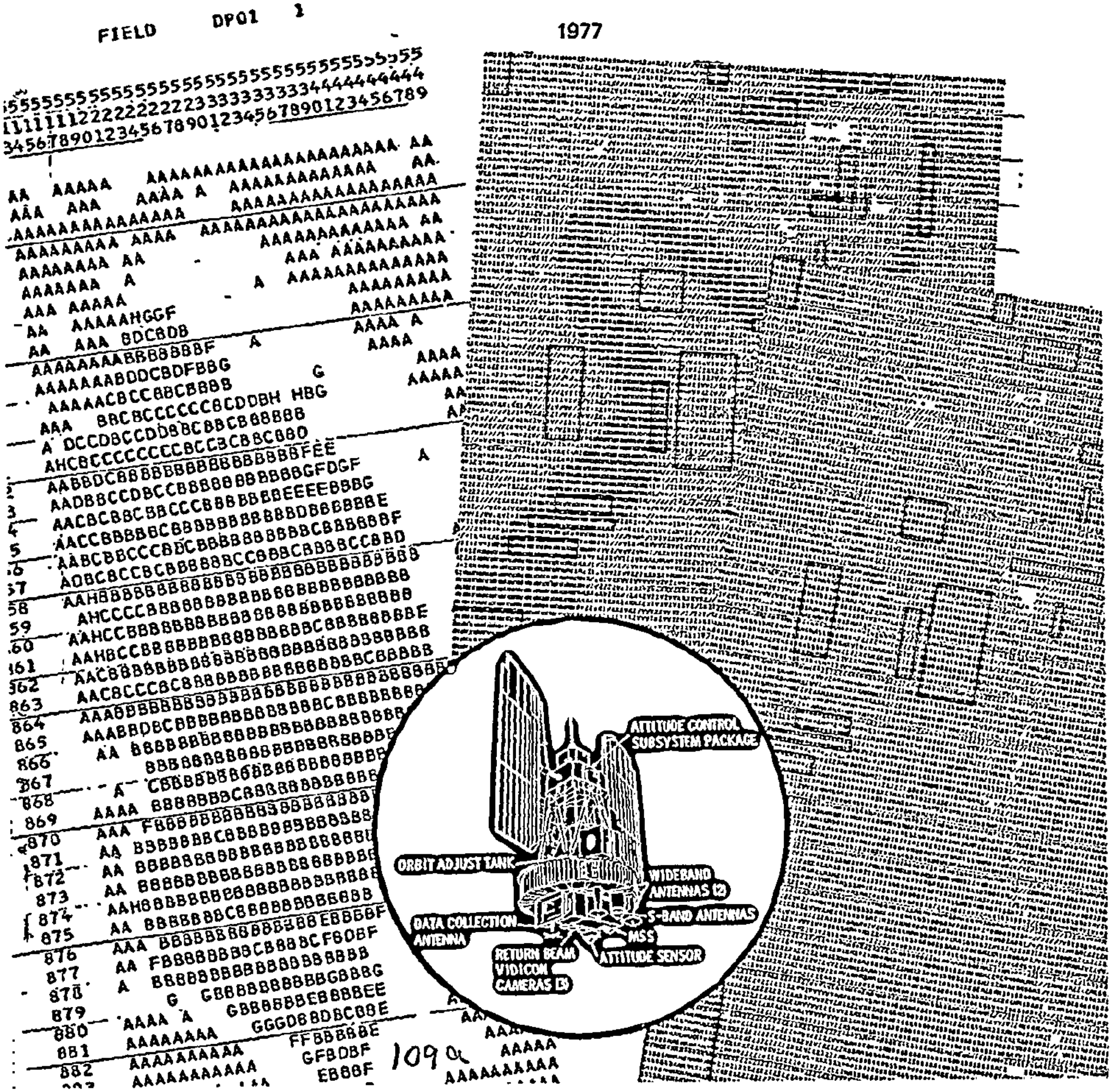
Computer Processing of Remote Sensing Data

ASIAN INSTITUTE OF TECHNOLOGY
REGIONAL COMPUTER CENTER

Submitted to

THE COMMITTEE FOR COORDINATION OF INVESTIGATIONS
OF THE LOWER MEKONG BASIN

1977



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ASIAN INSTITUTE OF TECHNOLOGY

March, 1977

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FINAL REPORT

ON

COMPUTER PROCESSING OF REMOTE SENSING DATA

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The authors wish to express their sincere thanks to Dr. Lee D. Miller for making available the computer program and his valuable suggestions, and the the AIT-RCC staff for their tireless helps in the development of the computer program and the preparation of this report.

ABSTRACT

This report describes the computer program development carried out by the Regional Computer Center of the Asian Institute of Technology for the classification of the information, recorded on the Computer Compatible Tapes, from the LANDSAT satellites as they pass over Thailand and the Lower Mekong Region.

The RECOG computer program package was selected and modified for this development work. Three classification approached employed in the computer are Level Slicing, Euclidean Distance and Maximum Likelihood decision schemes.

To demonstrate the capability of the program, which covered reservoir, estuary, deltaic area, mangrove area and road features were selected for the classification. Due to the difficult classification of the small subimages such as road and water way, an additional technique for image enlargement called the cubic convolution interpolation technique was added to the package.

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I. INTRODUCTION

Background

This report is prepared in accordance with the agreement (1) made between the Asian Institute of Technology (AIT) and the Committee for Coordination of Investigation of the Lower Mekong Basin (MEKONG Committee) on July 31, 1975 for the Regional Computer Center of the Asian Institute of Technology (AIT-RCC) to develop a computer software system which can interpret the information on the Computer Compatible Tapes (CCT) obtained from the LANDSAT and/or SKYLAB in passes over Thailand. Furthermore, software system must include data analytical algorithms which are based on pattern recognition methods utilizing statistical decision theory. In recent years a number of computer program packages was developed by several LANDSAT investigators in the United States to classify the multispectral data by statistical means. The purpose of this project is to adapt and/or modify available computer program package to operate on the AIT-RCC computer facilities and execute the classification approaches of forested area, estuary, reservoir and grassland. Of course, this development has done thus far was conducted jointly by the Asian Institute of Technology and the Mekong Secretariat.

LANDSAT-A and LANDSAT-B satellites were launched by the U.S. National Aeronautics and Space Administration (NASA) on

July 23, 1972 and January 22, 1975, respectively. During each orbit, at an altitude of 915 kilometers, the LANDSAT satellites view 185 km-wide strip from north to south to detect and record certain radiant energy reflected from the Earth's surface. The sun-synchronous orbit allows 14 orbits a day and coverage of the same area every 18 days at the same local solar time, which is 0942 hours at the equator(2). Due to time offsetting, these two satellites together provide 9 day coverage of some places every 9 days.

There are two sensing systems aboard the LANDSATS to detect the solar reflectance of the ground area at the visible and near infrared regions of the electromagnetic spectrum. Such systems are Return Beam Vidicon (RBV) system and a four band Multispectral Scanner (MSS) system. The MSS data has supplied vast information generating numbers of valuable applications (see Table 1).

Four band MSS system installed on board LANDSAT-A and LANDSAT-B has produced the separated data at wavelength from .5 to 1.1 micrometers. With the electromagnetic spectrum region shown in Figure 1, it can be seen that Band 4 (.5 - .6 μm) and Band 5 (.6-.7 μm) cover green and red bandwidths at the same time Band 6 (.7-.8 μm) and Band 7 (.8-1.1 μm) are in the near infrared region.

The number of bands or channels used with the MSS is not limited by the range of the electromagnetic spectrum. It depends on the application purpose. For instance, high flight aircraft has a 12 channel MSS and the LANDSAT-C has a 5 channel MSS. The Tabulation between type of MSS and the electromagnetic bandwidth is shown in Table 2.

LANDSAT Multispectral Scanner Data

The elementary unit of the LANDSAT imagery scene is a ground area of 185 x 185 square kilometers. Information sensed is transmitted as analog electronic signal. The analog electronic signals, together with internal calibration measurements are transmitted to the ground station where they are digitized and formatted into a digital data stream.

As information is recorded by the 4 channel MSS in the LANDSAT's, an imagery scene is four separated data pictures. Each picture contains approximately 8 million piece-wise elements. A pictorial element, pixel, represents a numerical value of the integrated spectral reflectance of the ground field approximately 50 meters by 80 meters along the satellite path. The numerical value of each spectral channel which is currently normalized to the range 0 to 63 is called gray shade. These gray shade values represent ground field properties and they are the numerical values in the computer compatible tapes.

Selection of Program Packages

The available program packages for analyzing and classifying the MSS data with the statistical concepts are: LARSYS(3) of Purdue University with computer IBM 360/67; WRL(4) of University of Michigan with computer PDP-8; KANDIDATS(5) of University of Kansas with computer PDP 15/45 and RECOG(6) of Colorado State University with computer CDC 6400. Each of the above packages has a certain degree of machine dependency with regards to the programming flexibility and the computer language usage. The machine dependency has to be considered since the computers used by each of the above packages differs from the computer facilities at AIT-RCC.

The RECOG package of Colorado State University was selected for implementation on the AIT-RCC's IBM 370/145 because :-

1) RECOG is a simplified version of the LARSYS and the WRL, and combines their elementary classification schemes, such as Level Slicing, Euclidean Distance and Gaussian Maximum Likelihood.

2) RECOG has minimum machine dependent language features.

3) RECOG programming structure was designed so that each of its work step is independent. Therefore, any additional work can easily be done without interfering other step operations.

4) The Input/Output handling routines can be modified to take advantage of facilities provided by IBM 370/145 and reduce the computer time requirements.

Furthermore, the result of the work completed not only to adapt the mentioned package to the IBM 370/145 facilities at AIT-RCC but also to improve its Input/Output handling system. As a result, the computer time consumption after the Input/Output handling improvement took less in the order of magnitude than the earlier unchanged version.

Scope of Work and Work Plan

In carrying out this developmental work, the project program was planned in three phases as follows:-

1) Study program functions of the RECOG package package and convert every machine dependent

language subroutine to FORTRAN subroutine;

2) Set up input test data corresponding to the grammatical words used in RECOG on the multispectral data of LANDSAT-A computer compatible tapes and improve the RECOG program package, such as eliminating redundant subroutines and re-organizing the Input/Output handling routines;

3) With the supplemental study on ground truth observation carried out from August 1975 to August 1976, the classification work would be performed on the LANDSAT-B computer compatible tapes over the areas which the ground observations were taken.

Due to the time limitation and the inavailability of LANDSAT-B computer compatible tapes, the work of the final phase was not possible. Instead, the classification was demonstrated over the areas in the vicinity of Bangkok and the Gulf of Thailand.

II RECOG PACKAGE

Historical Review

The RECOG program package has been available at Colorado State University since 1972. The programming developments and the basic classification concepts were carried out by J.A. Smith and his working group (8) so that the simplified algorithms of the LARSYS and WRL were applicable on the CDC 6400 at the Colorado State University computer facilities.

Initially, the RECOG organizer expected their package to work in both interactive and batch processing fashions. For the interactive mode, a RECOG user can use a remote terminal either to key in his desired command as an input or to display the statistical values as an output. With a colour television image display station, he can request for his image output display. Furthermore, the user can work in a batch processing mode independently by using the computer printer as an output device for both statistical value and image display. The organizers also aimed that all programs and subroutines of the package would have been written in FORTRAN language for easier transfer to other installations. Unfortunately, the package transference is inapplicable without extensive program modification due to the following three main reasons:-

1) The information content of the CDC 6400 computer is 60 bits per word. This constraint sets the file structure, especially the MSS data file, to be used with 60 bit word computer.

2) Time consumption and central memory constraint cause some of the program being written in CDC 6400 machine language.

3) The interfacing systems between the remote devices and the central computer CDC 6400 require some internal system subroutine.

Since the commencement of the project, extensive modification on the RECOG package has been carried out.

Modification of RECOG Package

The objective of the programming development is to develop a computer software system for interpreting the LANDSAT's MSS data from the computer compatible tapes using batch processing mode. Therefore, all program instructions involved with the interactive mode were first eliminated. The following work steps in modifying the RECOG package were then conducted:-

1) Changing the MSS data file structure so that it can be accessed by a 32 bit word computer.

2) Converting every machine language subroutines to FORTRAN subroutines.

3) Setting up input test data corresponding to the grammatical commands used in each RECOG phases.

4) Eliminating the duplicated subroutines which their differences were only the label common used in different program steps.

5) Reorganizing the sequential input-output files of the package to suit a random processing procedure which substantially reduces the Input-Output searching time.

6) Adding the cubic convolution technique (7) to RECOG package. The technique provides smooth computer print-out images and helps user in extraction of information in small subimage areas where individual pixels can be seen.

The above mentioned modification of the RECOG package was completely done and installed on the AIT-RCC computer

IBM 370/145. To distinguish between the original RECOG package and the modified one, the modified RECOG package was named RECOGX.

Classification Definitions and Techniques Used in RECOGX Package

The original classification approach used in the RECOG was defined by the LARSYS staff at Purdue University. The LARSYS and RECOG packages were prepared for the 12 channel MSS data with the technique called supervised learning. This technique which needs a trainable pattern categorizer is to be contrasted with unsupervised learning methods where little or no priori information is used before classification (6). The only technical addition made to the package is the cubic convolution interpolation concept.

The basic objective of RECOG is to recognize or classify the combination of the gray levels of the MSS data within the different electromagnetic bandwidths under the assumption that the gray tone combination of an interested view data collected at the different bandwidth can identify that specific field view from all others. Although the classification approach under such assumption is difficult to clarify practically for the real MSS data, the precision of work can still rely on either preprocessing transformation applications or the appropriate selection of training data.

Since all the mathematical descriptions employed in the RECOG package have been fully described in the Pattern Recognition Routines for Graduate Training in the Automatic Analysis of Remote Sensing Imagery manual publicized by College of Forestry and Natural Resources, Colorado State University, this report will brief the key functions and classification approaches employed in RECOG and the same mathematical notations described in such manual will also be used. Although the RECOG package has originally been described for the use of 12 channel MSS data, technically the concepts can still exist for the 4 channel LANDSAT data because it can be considered as a subset of the 12 channel data. The only distinction is the MSS data file whose information content consists of 4 separate data sets instead of 12. This is implied that the channel 1 to 4 in RECOG corresponds to Bands 4 to 7 of LANDSAT MSS data. For better understanding, the followed description will be pointed out by sample results shown in figures.

In RECOG, there are six computer-aid techniques linking the MSS data to the three classification concepts. These six computer-aid techniques are

-MSS Data Representation (Gray Map)

-Histogram

-Statistical Value (Covariance or Correlation Matrix Mean Vector and Standard Deviation Vector)

-Channel Graph Plot (Class Histogram)

-Statistical Graph Plot (Class and Coincident Spectral Plots)

-Channel Determination (Divergent Concept).

The three classification approaches are

-Level Slicing Decision Rule (LEVELS)

-Euclidean Distance Rule (EUCLID)

-Likelihood Rule Assuming Multivariate Gaussian Probability Density Functions (GLIKE)

MSS Data Representation (Gray Map): is a symbolic map produced by a computer printer under a procedure of assigning a computer symbol to a mutually exclusive subset of the MSS gray tone values. This gray map not only provides a user a convenient way to produce LANDSAT images but also permits the accurate matching of pixels. With the appropriated gray tone arrangement, the gray map of each channel can discriminate the different ground features. The sample of gray maps which have 15 distinguishable shades of the MSS data in Band 5 (channel 2) and Band 7 (channel

4) are shown in Figure 3 and Figure 4, respectively. The gray map is only a guidance meant to aid the user to learn what ranges of gray tone are related to his interested feature.

Histogram: is a graphical plot which shows the relation of the gray tone values and frequency of their occurrences. The horizontal axis represents the gray tone values and the vertical axis represents the frequency of occurrence for each gray tone. A histogram of the Band 5 MSS data which gives the gray tone distribution of the same area in Figure 3 is shown in Figure 6. From these two computer aid techniques, it can be seen that any interested feature may be represented by a range of gray tone values and its gray tone distribution is overlayed by some other features. For example, a symbol $ in the gray map Figure 3 appears not only at the mangrove forested area but also at the deltaic area. Statistically, we can represent an interested feature of a MSS data channel by mean of setting up a sample set whose mean and standard deviation can be computed. Furthermore, the relation of the feature among MSS data can be represented by a correlation matrix. Rectangles shown in Figure 3 and 4 are sample sets for several features. In RECOG, a set of rectangular areas which represents a same expected feature is called a class of training set and each rectangle is also called a field of training set.

Statistical Values (Covariance or Correlation Matrix, Mean Vector and Standard Deviation Vector): The classification approaches employed in RECOG use these statistical values as arguments for the computational algorithms. RECOG will provide all these statistical values in form of computer punch cards so that once they are sampled, they can be re-used with any additional training classes specified for later classification work. Sample outputs of correlation matrices, mean vectors, and standard deviation vectors for training set classes 'MON1', 'ROAD', and 'SWP1' are shown in Figure 9. Occasionally, some training classes are mis-selected and/or duplicated, thus there are two computer-aid techniques: channel graph plot and statistical graph plot, to inspect the behavior of the training classes.

Channel Graph Plot (Class Histogram): is a set of N-channel histograms for a training class. These histograms will help the user to inspect whether any mis-selected training data points occurred by giving a multimodal distribution. Figure 10 displays three selected training classes in channel 1 to 4 (or Band 4 to 7 according to LANDSAT).

Statistical Graph Plot (Class Spectral Plots and a Coincident Spectral Plot): is a plot which represents a class mean value and its standard deviation for an interclass comparison. Class spectral plots shown in Figure 11 indicates the statistical variation in gray tone values of the 4 channels. The center of the row of asterisks '*' is a specified class mean value and the length of the row presents plus and minus its one stardard deviation. The duplicated classes may be easily found by checking the displayed patterns of classes among channels. However, it takes quite some time for checking through. Therefore, RECOG provides a summarized spectral plot called a coincident spectral plot which coincides all the class spectral plots to one plot. From a coincident spectral plot shown in Figure 12, it can be seen that class A (Mangrove training area) and class D (Swamp area) are statistically the same in channel 2 (band 5) and are different in channel 4 (band 7). If there are any duplicated spectral plot of the training classes for various channels, one of them can be selected as their representatives or they can be re-defined as the same class sample points. So far, the described computer-aids have been used to select training classes. Time consumption is quite insignificant because the selecting procedures deal with several small subimages. However, the classification scheme, especially maximum likelihood decision rule, requires a considerable amount of computation. Furthermore, processing time increases rapidly and non-linearly with increasing channels and decreasing accuracy could actually result if all available channels are used (8). To determine which channels to use, RECOG uses the LARSYS divergence algorithm for selecting the best subset of channels to discrimate the classes of interest.

<u>Channel Determination</u>: is a process of selecting the best M subsets of the given N channels from the N given mean vectors and covariance matrices. This divergence algorithm is described by Marrill and Green (9). Sample output of channel determination shown in Figure 14 was computed from the given class mean vectors and covariance matrices of 4 MSS channels, the divergence between all pairs of classes as a function of channels. RECOG will print the channel combination divergence corresponding to a descending order of the divergence measures. The greater the divergence, the better the channel combination.

Next consideration is to use the appropriated decision rule for an accurate, fast, and economic classification. The following classification descriptions discuss the nature of each classification approach, its accuracy and time consumption.

A Level Slicing Decision Rule (LEVEL): assigns a class type to a data pixel whose gray tone value is in the range of the given minimum and maximum values of each selected channel. LEVELS is the simplest and fastest computational algorithm because the given ranges can be thought of as entries to a table look up. For example, Table 3 indicates that any sample pixel is assigned to a class type 'H', if its gray tone value is in the range 12 to 13 of Band 5 and in the range 3 to 5 of Band 7.

Although LEVELS is the fastest algorithm, there are two misleading assumptions:

1) every value of the given minimum and maximum range has equal probability of occurrence;and

2) each class type has uniquely been specified by the given range. This assumption is not always true because some class types can have an overlapping gray tone distribution.

Due to these misleading assumptions, both error of omission and error of commission can be rapidly increased. Sample output of a LEVELS recognition map is shown in Figure 17.

<u>An Euclidean Distance Rule (EUCLID)</u>: assigns a class type based on a classified boundary which is specified by the given class mean vectors and standard deviation elements of the given class covariance matrices. This classification scheme give some controls to a RECOG user who knows the nature of his interested sample area. Each classified boundary can easily be adjusted by changing a control parameter which is a function of the means and standard deviations. However, it takes longer time to decide what given class type a sample pixel <u>X</u> belongs to since a statistical distance of <u>X</u> with respect to the center of each boundary is needed to determine.

The Euclidean distance is measure of closeness between the unknown sample vector <u>X</u> and the mean vector <u>M</u> for the class under consideration weighted by the variance of the mean value in each channel. With the covariance information ignorance, EUCLID treats the gray tone distributions as statistical independent across channels. This is quite some obstructions to the classification results because the correlation of the data nature across channels has somewhat significant dependency. These can be seen from the correlation coefficient element of the sample output in Figure 9. There are at least two practical procedures to maximize correct classifications and minimize misclassification. First, a principal component transformation on the data to derive linear combinations of channels which are independent must be performed to fit the EUCLID. Secondly, numbers of of several iterations to adjust the control parameters must be trailed so that the relevant closeness distance between mean and sample is well specified in the overlapping area of the different boundaries. This is quite troublesome and it takes longer operations to interface between the automated processing and man decisions. Sample output for an Euclidean recognition map is shown in Figure 20.

The Gaussian Maximal Likelihood Ratio Rule (GLIKE): uses conditional multivariate Gaussian probabilities to assign a class type according to its highest given probability toward a sample pixel. Under the assumption that the interested sample data are normally distributed, this rule is the most accurate classification scheme requiring a considerable amount of computation time.

Owing to the highest probability assignment, every sample point in a given data map will be assigned even in the overlapping boundaries. Therefore, the degree of accuracy depends on how many classes can cover the overall boundaries and how likely the gray tone distributions behave as a Gaussian distribution. If any multimodal distribution of a desired class occurs, we can simply split it up into several subclasses which may then be more normally distributed. After all processing, the recognition results from these subclasses may then be combined. In most cases, the error of commission effects the GLIKE decision rule because fewer classes are specified for classification scheme. One way to compensate this error type is to reject the classified sample point which do not exceed a certain confidence level or threshold. This substantially has the effect of thresholding out an unknown sample pixel which does not really belong to the defined classes. Sample outputs of the recognition maps are shown in Figure 22, 25 and 27. Figure 25 and 27 display the GLIKE recognition map associated with the thresholding values. Furthermore, Figure 27 shows that two subclasses of water type are combined.

As mentioned, the RECOGX package contains a cubic convolution interpolation technique which is recommended by P.V. Wiu (7). This technique provides smooth computer print-out images and will help users in extraction of information in small subimage areas which individual pixels can be seen. It is implied that any small subimage area which was previously difficult to be defined as a class type in RECOG such as roads can be enlarged by using this technique. Sample outputs for the originated subimage and the enlarged one are shown in Figure 28 and 29, respectively.

Use of RECOGX

According to the Generation and Physical Characteristics of the MSS System Corrected Computer Compatible Tapes publication, a LANDSAT imagery scene is divided into four imagery strips each of which consists of approximately 820 pixels wide and 2340 pixels long. In order to obtain the MSS data in the CCT which includes information from all four spectral bands, the data from the bands are combined in process called interleaving. This is an operation in which two bytes of data from each band are interleaved to produce an eigth-byte group, which is the smallest element of interleaved data. Therefore, a pre-processing step of RECOGX is to convert each imagery strip of interleaved data to be four separate data sets within a computer file called a RECOGX reformatting file. The RECOGX reformatting file also provides imagery coordinates, 1-824 column-wise and 1-2340 row-wise, to the RECOGX user for refering his interested areas to the RECOGX programming steps.

There are six programming phases of the RECOGX package for the user to extract and classify his interested subimage. The following six programming details associated with their control cards and output summaries are as described below:

Phase I This phase is used in conjunction with ground information to select training and test fields. It reads the spectral data from a RECOGX reformatting file and displays selected channels of desired area in form of gray map. An optional histogram of data distribution in the specified area can also be plotted.

Figure 2 displays the control cards requested by the user to print a gray map of MSS data in Band 5 and 7 for the Mangrove area around the Bang Pakong Estuary. The selected area according to the RECOGX coordinates is lines 445 to 565, every line, and columns 387 to 506, every column. Fifteen distinguishable gray tone ranges are given corresponding to the specified symbols in the 'CHARACTERS' and 'XCHA' commands. The gray map outputs of Band 5 and 7 according to the control cards of Figure 2 are shown in Figure 3 and 4, respectively.

Figure 5 is the control cards requesting for band 5 histogram of the Figure 3 area and the histogram plotted by PHASE I shown in Figure 6.

<u>Phase II</u> This is a statistical processor for the training fields selected after studying Phase I output and ground information. The first statistical information printed consists of a correlation matrix, a mean vector, and a vector of standard deviation for each selected channel. Only the lower triangular portion of the covariance matrix and mean vector of each field are punched on cards which will be used for classification purpose in Phase III, Phase IV and Phase V. Histograms of the data distribution for selected channels in each field will be displayed to check if there is any fault selection training class. The class spectral plots and a coincident spectral plot will be printed as the last step to show the combination between the selected channels and the selected classes.

Figure 7 shows the control cards used for Phase II indicating that the user selected 7 training classes from the Gray map of Figure 3 to get their statistical values. The rectangles indicated in Figure 3 and 4 are the selected fields of these seven training classes which are composed of 3 classes of distinct water levels, 2 classes of swamp area, one for mangrove forested area and one for road. Each field of these seven classes refers to the RECOG coordinates indicated by line and column number. The control cards request the following statistical results:

1) Statistics for all defined classes; correlation

matrices, mean vectors, and standard deviation vectors will be printed; covariance matrices and mean vectors will be punched.

2) Histograms for channel 1, 2, 3, 4 (or Band 4, 5, 6, 7) and all classes.

3) Class spectral plots for all classes.

4) A coincident spectral plot.

First, Phase II sorts the input data cards and summarizes the information as indicated in Figure 8. The correlation matrices, mean vectors and standard deviations for three of the seven classes are printed and shown in Figure 9. Due to the symmetrical property of the covariance and correlation matrices, only their lower portion of matrices are punched and printed, respectively. The correlation matrix will show the most and the least correlations among the selected channels for each class. Sample histograms for three classes of mangrove area, road, and swamp area for channel 1 to 4 are shown in Figure 10. The class spectral plots for these three classes indicating the statistical variation in gray tone for each selected channels are given in Figure 11. The center of the row asterisks '*' is the mean value and the length of the row represents plus and minus one standard deviation. The last output shown in Figure 12 is a coincident spectral plot representing the spectral plots of all classes within a channel to compare and check whether there is any duplicated class.

The results of Figure 10, 11 and 12 depict the interclass comparisons to serve the following three different purposes:-

1) The maximum and minimum gray tone values in each channel for each class can be used as parameters for the level slicing classification process.

2) The more disjoint of the gray tone distribution in each channel the better a classification will be resulted. The separation or overlapping distribution can be inspected from the class spectral plots and coincident spectral plot. If there is any overlapping distribution, this may result to divide such class into several subclasses.

3) For the better GLIKE classification work, the unimodality of each class histogram must be examined. The multimodal distribution of a training class may cause greater commission error.

Phase III The program computes the divergence between all pairs of classes as a function of channels. It will select the ten optimum wavelength channels which can best discriminate between the fields of interest to the best of the divergence values. Figure 13 shows the input control cards requesting the best two of four channels for the given seven classes. A distance measure has been determined for all pairwise combinations of the seven classes and for all C_2^4 ways of selecting 2 channels from the 4 channels possible. For each channel combination, the minimum distance, the maximum distance, and the average distance have been calculated and the channel combinations sorted according to decreasing average pair-wise distances. Only the ten most significant combinations are printed like Figure 14. Unfortunately, the divergence criteria suffers from not having an absolutely calibrated distance scale and by relying so heavily on user interaction for interpretation of results. That is, a divergence distance of 10.7 means nothing by itself, but only in comparison to other pair-wise distance for other classes. By comparing divergence distance between the best two selected channels 3-4 and channels 2-4, channels 2-4 selection has better discrimination because most of the pair distances are higher. Therefore, channels 2 and 4 are selected for the following classification processes.

Phase IV This is a preclassification precessor intended for an experimental categorial assignment regarding the decision schemes. Such decision schemes are level slicing, Euclidean distance and Gaussian likelihood ratio. The program reads the MSS data from a RECOGX reformatting file and reads the statistical value arrangements of the defined classes, that is, the level slicing classification requires only the maximum and minimum values of each class in the selected channels while the Euclidean distance and Gaussian likelihood ratio classifications require covariance matrices and mean vectors of the selected classes. The recognition map and summary table which contains number of pixels for each categorial assignments will be printed. Figure 15 displays control cards requesting for level slicing decision scheme. Given statistical maximum and minimum gray tone values of channel 2 and 4 for the 15 different water levels, the classified area is at Bang Pra reservoir whose RECOGX coordinates are lines 837 to 889 and columns 513 to 549. First Phase Iv sorts the input cards, assigns a recognition map symbol to each class, and summarizes the information in the table form shown in Figure 16. The recognition map and the summary table are shown in Figure 17 and 18, respectively.

Figure 19 shows the input control cards for using the Euclidean distance classification EUCLID. As we previously described in the last section, Euclidean decision rule required a thresholding value per class for its classification scheme. In this case, the thresholding value of every class is assigned a value of 1. With the given mean vectors, covariance matrices, thresholding value, training field coordinates and the best two selected channels, the recognition map of the same area in the gray map Figure 3 and 4 is shown in Figure 20.

Figure 21 shows the control cards requesting for the Gaussian likelihood ratio decision scheme GLIKE. Without the thresholding control cards, the input data for GLIKE are the same as in Euclidean one. The GLIKE recognition map of the same area classified by the EUCLID is shown in Figure 21. Since this decision scheme is based on the highest conditional probability of the given classes, the recognition map of Figure 21 provides the classified characters to every pixel even though some of them do not really belong to the defined classes. As a result, Phase V and VI were written to reject the classified pixels whose conditional probabilities do not exceed a certain confidence level or thresholding values according to the Chi-square table.

<u>Phase V</u> Only the Gaussian likelihood ratio scheme will be used for this final classification. Phase V will classify the given MSS data from a RECOGX reformatting file according to the covariance matrices and the mean vectors for the defined classes in the selected channels. Then an

output recognition map which contains the assigned category and its highest conditional probability will be written in a computer file for the use in Phase VI.

Figure 23 shows the control cards requesting for a Gaussian maximal likelihood decision scheme GLIKE with the same classifying area, covariance matrices and mean vectors of the same assigned classes as given in Phase IV EUCLID and GLIKE schemes. Symbols have been specified for each class from the control card set: A for mangrove area, E,F and G for three different water level, C and D for two distinct swamp areas, and B for road. If the classification process is successfully executed, the comment, FILE WRITTEN ON TAPE 8 is printed.

Phase VI The purpose of this phase is to threshold out every assigned category which does not really belong to any of the assigned classes. With the number of channels used in Phase V and the given thresholding index for Chi-square table in Phase VI, every misclassified pixel whose condiitonal probability does not exceed the given thresholding value will be rejected. To obtain a thresholding value from the Chi-square look up table in Phase VI, the required entries of this table are number of channels used in classification and a thresholding index. This thresholding index is a set of integer value varying from 0 to 10. If 0 thresholding index specifies on a classified class, no rejection process will conduct to that class. Elsewhere, any thresholding index between 1 and 10 will cause Phase VI to threshold out a percentage of points corresponding to the following table.

Thresholding Index	Percent Thresholded Out
1	0.1
2	0.5
3	1.0
4	2.0
5	2.5
6	5.0
7	10.0
8	20.0
9	25.0
10	50.0

Figure 24 shows the control cards and header information requesting to the thresholding indices: 4 for 'MON1' (mangrove area), 7 for 'ROAD' (road class), 2 for 'SWP1' (swamp area), 3 for 'SWP2' (shallower swamp area), and 1 for 'WTR1', 'WTR2', and 'WTR3' (three distrinct water level). The thresholding recognition map corresponding to this request is shown in Figure 25.

Figure 26 shows the control cards and header information for the increased thresholding indices and the re-assigned symbols for the seven defined classes. The outputs of recognition map and the number of final classified pixels for each class are shown in Figure 27.

In fact, the degree of accuracy or confidence in this final classification depends on how the training class behaves as a normal distribution in the selected channels and what qualification of the ground area appropriates for the training class. With the six computer-aid techniques and three classification schemes in RECOG package, and the additional cubic convolution technique, a final classification work can be accomplished through the six programming phases in RECOGX.

III APPLICATION SAMPLES

During the RECOG package modification period, the following two imagery CCT's of LANDSAT-A were available at AIT Regional Computer Center:-

1) E1167.HO3070 which covers the south eastern part of Thailand is taken on the passing date January 6, 1973.

2) E1168.HO3122 which covers Thailand central plain including Bangkok is taken on the passing date January 7, 1973.

Two RECOGX reformating files which contain the second strip of E1167.H03070 and the fourth strip of E1168.H03122 has been stored in disk pack of the IBM 370/145. The second strip of E1167.H03070 covers mangrove forestry area, Bang Pakong River, BangPra Reservoir and the eastern beaches of Thailand and the fourth strip of E1168.H03122 covers Bangkok, Don Muang Airport, Rang Sit area, Wang Noi, Ayuthya and Lopburi provinces. According to the LANDSAT photographic imageries, these two scenes had less cloud coverage and are very clear in every band. Therefore, the test run and classification trails were processed based on these two reformating files. Furthermore, these imagerial scenes, south central plain and the southern part of

Thailand scenes for several passes of LANDSAT-B were ordered from US EROS data center at the end of January 1976. Unfortunately, the only two scenes were received at AIT-RCC at the end of September 1976. These two scenes are:-

1) E2073.H02552 which is the same area as E1167.H03070 is taken on the passing date April 5, 1975; and

2) E2182.H03014 which covers the southern part of Thailand including Prajuab province is taken on the passing date July 23, 1975.

Approximate 85 percent of these two scenes are cloud coverage and the rest of the scene is most probable distorted by shadow of the high thin cloud.

As a result, the areas used in this report for the three classification approaches and the cubic convolution interpolation technique are based on the second strip of E1167.H03070 and the fourth strip of E1168.H03122. Geographically, the areas used from the second strip of E1167.H03070 are:-

1) Mangrove area around the Bang Pakong estuary;
2) Bang Pra reservoir;
3) Deltaic area of lower Bang Pakong estuary; and

the areas used from the fourth strip of E1168.H03122 are:-

1) Rang Sit area including the intersection between Pahonyotin highway and Rang Sit cannel

2) Wang Noi District.

Level Slicing Classification:

As stated under level slicing decision definition, the distribution of any feature under this classification scheme ought to be non-interest uniform distribution. By studying several class histogram of the given training classes, an non-overlapping distribution in Band 7 of the deep water, such as reservoir and sea water, is found. Two selected areas for this classification are Bang Pra reservoir and deltaic area of lower Bang Pakong estuary. Gray maps of Bang Pra reservoir in Band 5 and 7 are shown in Figure 30 and a gray map of deltaic area of lower Bang Pakong estuary in BAND 5 is shown in Figure 32. From Figure 31 and 33 which are the class histogram of Bang Pra reservoir and deltaic area, respectively, we can see that the water feature gives the unimodal distribution for both Band 5 and 7. To avoid the misclassification due to the uniformity of the distribution we can simply divide the distributions into several sub-region as the sub-division of the level slicing region shown in Table 3. The level slicing recognition maps for Bang Pra reservoir and the deltaic area of the lower Bang Pakong river are shown in Figure 17 and 34, respectively.

<u>Euclidean Distance and Gaussian Maximal Likelihood Classification Schemes</u>:

As earlier mentioned, these two decision schemes require the statistical values from the defined classes as their input parameter. Euclidean will classify the MSS data based on classified boundary constructed by the class mean and standard deviation regardless of the interchannel relation. In case of the overlapping distribution, the decision rule will discrimate what class to be assigned from the closeness of the statistical distance. This substantially provides a user some control to his results. Meanwhile, Gaussian decision scheme require only the unimodal distribution of the training classes. It classifies an unknown pixel to a class whose conditonal probability is highest. The misclassification potential of Euclidean is error of omission while of Gaussian is error of commission. Certainly, the classifying area for these two classification scheme must have serval features whose sub-area is large enough to specify a training set for each feature. The selected area for these decision schemes is mangrove area around the Bang Pakong estuary. Its gray maps in Band 5 and Band 7 are shown in Figure 3 and 4. The rectangles in both gray maps are training fields which are set up for mangrove (MON1) class, three distinct water level sub-classes (WTR1, WTR2 and WTR3), two distinct swamp area sub-classes (SWP1 and SWP2) and road feature (ROAD). These rectangular locations corresponding to the RECOGX coordinates are indication in Figure 7. By class histogram comparison, the road training class gives the worst gray tone distribution as shown in Figure 10. From the output punch cards of the statistical values, the divergent concept employed in Phase III of RECOG indicates that the best two channel for decision schemes are channels 3-4 and 2-4. The combination of channels used for these decision schemes are 2-4 because most of the statistical pair distances of 2-4 combination are higher than 3-4 combination as shown in Figure 14. The Euclidean recognition map of this mangrove area with the thresholding value 1 for every defined class is shown in Figure 19 and the Gaussian recognition map of the same mangrove area is shown in Figure 22.

Gaussian Maximal Likelihood Ratio Associated with the Chi-square Table:

Geographically, the road classified pixels, appear in the GLIKE recognition map Figure 22, have some contradictories against its nature such as numbers of single disconnected road pixel spread over the mangrove area and the road width in some places is too wide according to the described pixel size. The statistical reasons behind this misclassification result are :

1) the selected training subimage for the road class too small to exclude the non-road pixel and thus the road distribution shown in Figure 10 are not normally distributed for any channel; and

2) the gray tone range of the road class in each channel is at the middle of the band range. Hence, the unknown classes which do not close to any other defined classes tend to be assigned to the road class owing to the highest conditional probability criterion.

Eliminating the misclassified pixel is to use the Gaussian maximal likelihood ratio criterion with the Chi-square table. From Figure 25 and 27, thresholding indices given to the road class are 7 and 9,respectively. This indicates that the better possibility of the classified road pixel should be. However, the thresholding values of the Chi-square table do not effect the classified pixels which are strongly connected within the class. For example, numbers of classified pixels for the 'WTR1', 'WTR2', 'WTR3' and 'SWP1' do not decrease even though their thresholding indices are up to 4. The numbers of classified pixels for each classes can be seen from the summarized table in Figure 22,25 and 27. Moreover, some of the classified symbols in Figure 27 can be re-assigned for the sub-classes composition ('WTR2' and 'WTR3' are assigned to 'G' symbol) and for the image enhancement ('MON1' as M and 'ROAD' as I).

The similar trail has applied to the Wang Noi District whose area is in the fourth strip of the E1168.H03122. However, the Wang Noi area covers so many tiny features such as artificial waterway, bare ground and harvested rice field, while the mangrove area around the Bang Pakong estuary covers most of the main feature. The final recognition map at Wong Noi District with 10 distinct feature shown in Figure 35.

Cubic Convolution Interpolation Technique:

According to the difficulty of the small training selection, RECOGX includes a cubic convolution interpolation technique introduced by P.V. Wiu and his working group(7). The computer program was written to enlarge the small subimage whose coordinates are known from a RECOGX reformatting file. The output file of the enlarged subimage was organized in the same fashion as the RECOGX reformatting file so that every programming phase can access it without any grammatical command changed. The Band 5 small subimage of the Rang Sit area that covers the intersection of the Pahonyotin highway and Rang Sit canal (Figure 28) is selected for this technique. The gray map of the 10 x 10 enlarged subimage for the mentioned area in Band 5 is shown in Figure 29.

IV SUMMARY

RECOG package of Colorado State University was selected for implementation on the IBM 370/145 at AIT-RCC to classify and interpret the informaiion on the Computer Compatible tapes obtained from the LANDSAT in passes over Thailand. Due to the computer system difference, six modifying steps were conducted to adapt the RECOG package to suit the AIT computer facilities and to improve the performance. Furthermore, the cubic convolution interpolation technique was added to the modified package to allow more efficient selection of the small training field. To distinguish between the original and modified RECOG package, the modified package was named RECOGX.

The basic objective of RECOGX is to recognize and classify the combination of the LANDSAT Multispectral Scanner Data in the Computer Compatible Tapes. These information interpretation and classification work can be performed by using six computer-aid techniques and three classification decision schemes from the RECOGX package. Two of these three decision schemes provide a user a control parameter, that is, with the statistical value of the selected training field the classification results can be controlled by changing the parameter indices.

Two strips of the different LANDSAT-A imagery scenes were selected for these classification works. The classified areas were Mangrove area around the Bang Pakong estuary, Bang Pra reservoir, deltaic area of lower Bang Pakong estuary and Wong Noi District. The small subimage to test the image enlargement of the cubic convolution technique is Rang Sit area including the intersection between Pahonyotin highway and Rang Sit canal. However, it was the initial intention to classify some of the mentioned areas from the LANDSAT-B computer compatible tapes. Unfortunately, it is not possible to process such data in time due to the late delivery of LANDSAT-B CCT. Moreover, the late received LANDSAT-B imagery scene covered by cloud coverage approximately 85 percent.

Although a question of the ground truth observations corresponding to the LANDSAT passing date of the classified scene has been left unanswered by this report, the classification results promisingly indicate that the road feature and the waterway can be identified by the use of the computer-aid techniques and the classification decision schemes. Future research should focus on refinement of the ground measurement settings to improve the accuracy of the classification work.

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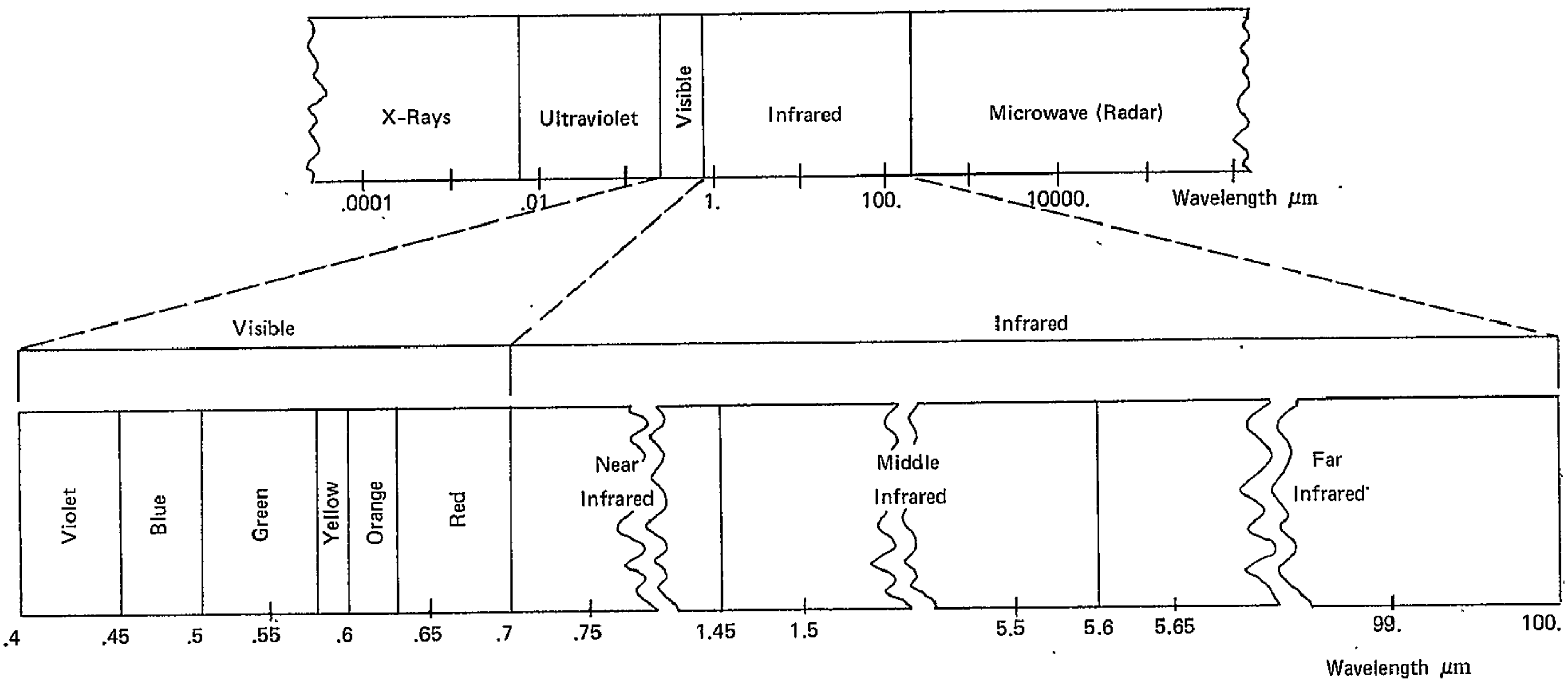

Figure 1: Electromagnetic spectrum.

REMOTE SENSING DATA ANALYSIS

PHASE ONE

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$$$$$$$$$$$$$$$$$$$$   GROUP OF CONTROL CARDS ENCOUNTERED   $$$$$$$$$$$$$$$$$$$$

$ GRAYMAP
INPUT 9 FILE 1 CHAN 2 TAPE ERTS5 LINE 445,565,1 COLU 387,506,1
TIME 9.30 RUN 1 DATE NOVEMBER 20,1976 ALTITUDE 9999 FEET
FLIGHT LINE AITRCC GROUND HEADING 180 DEGREES NCHA 15
RANS 7-10.5,10.5-11.5,11.5-12.5,12.5-13.5,13.5-14.5,14.5-15.5,15.5-16.5
RANS 16.5-19.5,19.5-21.5,21.5-25.5,25.5-30.5,31.5-35.5,35.5-40.5,40.5-45.5
RANS 45.5-63.5
CHARACTERS MX$BM*XZVI/=+-
XCHA W)*I
NLEV 100
$ BEGIN

$ GRAYMAP
INPUT 9 FILE 1 CHAN 4 TAPE ERTS5 LINE 445,565,1 COLU 387,506,1
TIME 9.30 RUN 1 DATE NOVEMBER 20,1976 ALTITUDE 9999 FEET
FLIGHT LINE AITRCC GROUND HEADING 180 DEGREES NCHA 15
RANS 0-2.5,2.5-4.5,4.5- 5.5, 5.5- 7.5, 7.5-11.5,11.5-15.5,15.5-17.5,17.5-18.5
RANS 18.5-19.5,19.5-20.5,20.5-22.5,22.5-23.5,23.5-24.5,24.5-26.5,26.5-28.5
RANS 28.5-31.5
CHARACTERS MX$BM*XZVI/=+-
XCHA W)*I
NLEV 100
$ BEGIN

CONTROL CARD ERROR DIAGNOSTICS

**********   NO FATAL ERRORS ENCOUNTERED   BEGIN EXECUTION   ***********
```

Figure 2: PHASE I CONTROL CARD. Two sets of control cards request for graymap of the MSS data in Band 5 and 7 for the Mangrove area around the Bang Pakong Estuary.

REMOTE SENSING DATA ANALYSIS

PHASE ONE

G R A Y M A P

RUN NUMBER	1	DATE	NOVEMBER 20, 1976
FLIGHT LINE	AITRCC	TIME	9.30
TAPE NUMBER	ERTS5	ALTITUDE	9999 FEET
FILE NUMBER	1	GROUND HEADING	180 DEGREES

GRAYMAP OF CHANNEL 5 OF 7 CHANNELS

CHANNEL 5 SPECTRAL BAND 0.60 TO 0.70 MICROMETERS

THE CHARACTER SET USED FOR DISPLAY ISO

FROM	7.00	TO	10.50	DISPLAYED M	FROM	14.50	TO	15.50	DISPLAYED *	FROM	25.50	TO	30.50	DISPLAYED /
FROM	10.50	TO	11.50	DISPLAYED I	FROM	15.50	TO	16.50	DISPLAYED X	FROM	31.50	TO	35.50	DISPLAYED =
FROM	11.50	TO	12.50	DISPLAYED *	FROM	16.50	TO	19.50	DISPLAYED Z	FROM	35.50	TO	40.50	DISPLAYED +
FROM	12.50	TO	13.50	DISPLAYED 8	FROM	19.50	TO	21.50	DISPLAYED V	FROM	40.50	TO	45.50	DISPLAYED -
FROM	13.50	TO	14.50	DISPLAYED M	FROM	21.50	TO	25.50	DISPLAYED I	FROM	45.50	TO	63.50	DISPLAYED

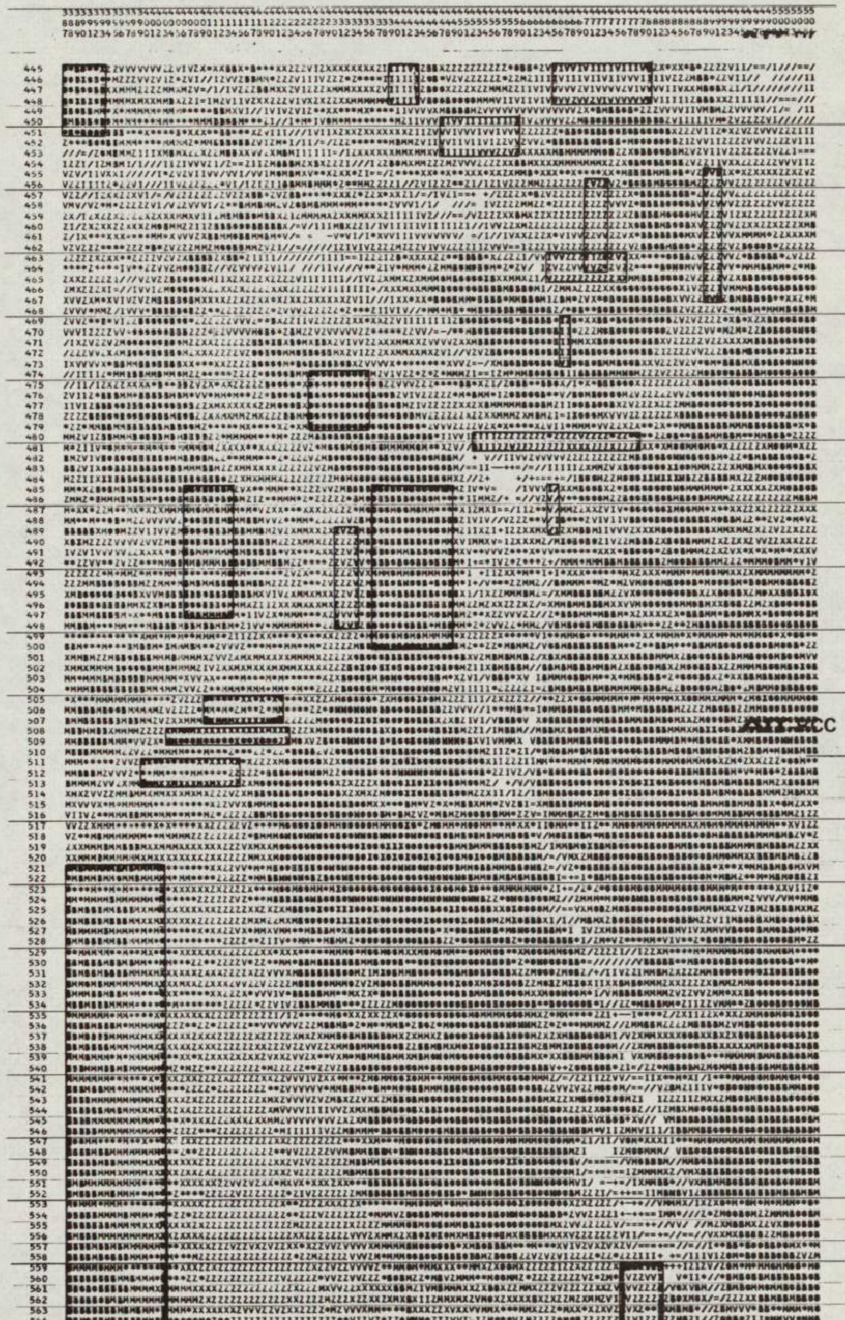

Figure 3: PHASE I GRAYMAP OF BAND 5. The grayscale printout with 15 different symbols resulting from the top set of control cards request of Figure 2 has been printed. Rectangulars are training sets that will be used for classification approaches.

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REMOTE SENSING DATA ANALYSIS

PHASE ONE

G R A Y M A P

RUN NUMBER	1	DATE	NOVEMBER 20, 1976
FLIGHT LINE	AITACC	TIME	9.30
TAPE NUMBER	ERTS5	ALTITUDE	9999 FEET
FILE NUMBER	1	GROUND HEADING	180 DEGREES

GRAYMAP OF CHANNEL 7 OF 7 CHANNELS

CHANNEL 7 SPECTRAL BAND 0.80 TO 1.10 MICROMETERS

THE CHARACTER SET USED FOR DISPLAY ISO

FROM	0.0 TO	2.50	DISPLAYED	■	FROM	11.50 TO	15.50	DISPLAYED	*	FROM	20.50 TO	22.50	DISPLAYED	/
FROM	2.50 TO	4.50	DISPLAYED	I	FROM	15.50 TO	17.50	DISPLAYED	X	FROM	22.50 TO	23.50	DISPLAYED	=
FROM	4.50 TO	5.50	DISPLAYED	●	FROM	17.50 TO	18.50	DISPLAYED	Z	FROM	23.50 TO	24.50	DISPLAYED	+
FROM	5.50 TO	7.50	DISPLAYED	$	FROM	18.50 TO	19.50	DISPLAYED	V	FROM	24.50 TO	26.50	DISPLAYED	-
FROM	7.50 TO	11.50	DISPLAYED	M	FROM	19.50 TO	20.50	DISPLAYED	I	FROM	26.50 TO	28.50	DISPLAYED	

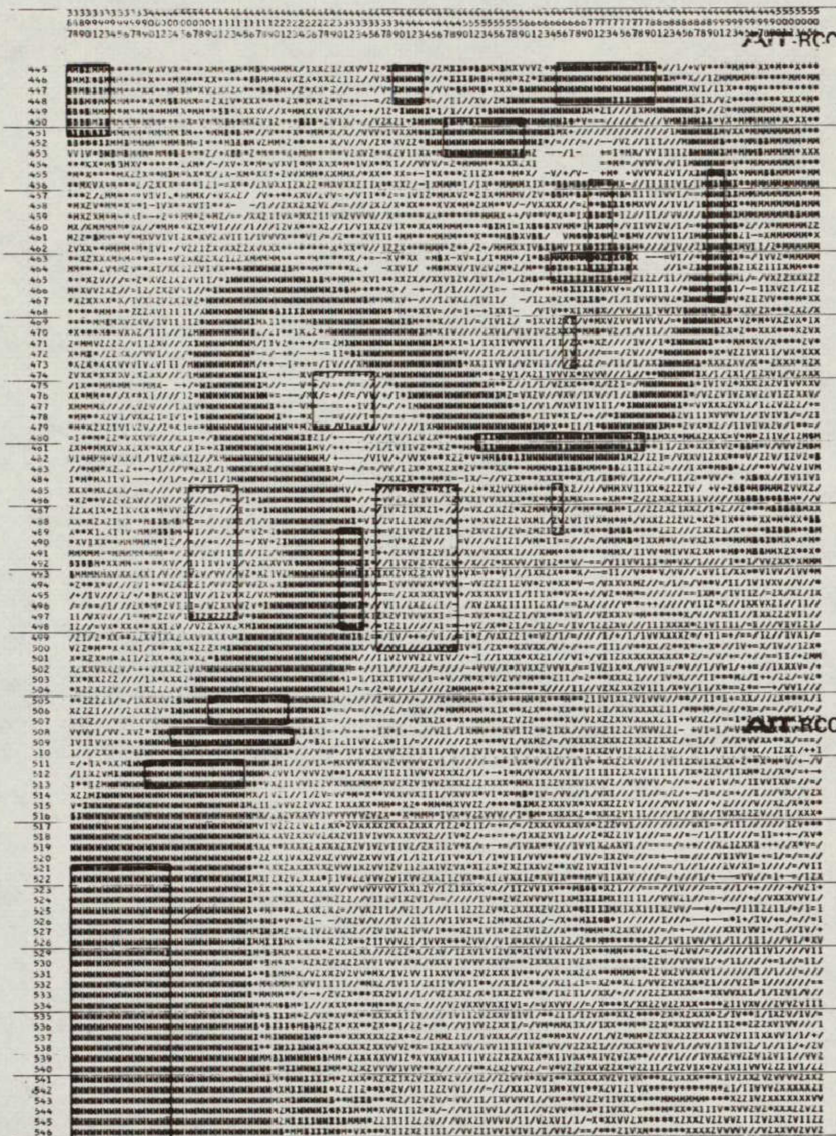


Figure 4: **PHASE I GRAYMAP OF BAND 7.** The grayscale printout with 15 different symbols resulting from the bottom set of control cards request of Figure 2 has been printed. Rectangulars are training sets that will be used for classification approaches.

```
REMOTE SENSING DATA ANALYSIS

PHASE  ONE

$$$$$$$$$$$$$$$   GROUP OF CONTROL CARDS ENCOUNTERED   $$$$$$$$$$$$$$$

$ HISTOGRAM
INPUT 9 FILE 1 CHAN 2 TAPE ERTS5 LINE 445,565,1 COLU 387,506,1
TIME 9.30 RUN 1 DATE NOVEMBER 20,1976 ALTITUDE 9999 FEET
FLIGHT LINE AITRCC GROUND HEADING 180 DEGREES
$ BEGIN

CONTROL CARD ERROR DIAGNOSTICS

*****     NO FATAL ERRORS ENCOUNTERED     BEGIN EXECUTION     ******
```

Figure 5: PHASE I CONTROL CARD FOR HISTOGRAM. A set of control cards requests for a histogram of the MSS data in Band 5 for the area of Figure 3.

REMOTE SENSING DATA ANALYSIS

PHASE ONE.

HISTOGRAM OF RADIANCE

CHANNEL 5   SPECTRAL BAND 0.00 - 0.70 MICROMETERS

EACH * REPRESENTS 86 POINTS

```
 2580 I             7
      I             *
 2408 I             *
      I             *4
 2236 I            7**
      I            ***
 2064 I            ***
      I            ***
 1892 I            ***
      I            ***
 1720 I            ***
      I            ***
 1548 I            ***
      I            ***3
 1376 I            **** 2
      I            ****5*
 1204 I            ******
      I            ******
 1032 I            ******
      I            ******
  860 I            ******
      I            ******
  688 I            ******
      I            ******99
  516 I            ******** 4
      I            ********9*
  344 I            **********
      I            **********56
  172 I          14************4   2
      I          ***************869*543143311 1
      I----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
     0.0                 20.00               40.00               60.00               80.00              100.00
```

Figure 6: PHASE I HISTOGRAM. The histogram printout resulting from the control cards request of Figure 5. The horizontal axis represents the gray tone value. The vertical axis represents the frequency of occurrence for each gray tone. In this particular example, each * represents 86 pixels. The numerical digits (1–9) indicate the fraction (0–100 percent) of 86 pixels that occurred for the gray tone value.

REMOTE SENSING DATA ANALYSIS

PHASE TWO

```
$$$$$$$$$$$$$$$$$$$$  GROUP OF CONTROL CARDS ENCOUNTERED  $$$$$$$$$$$$$$$$$$$$

$ STAT CLAS ALL
$ HIST CLAS ALL
$ HIST CHAN 1 2 3 4
$ SPEC CLAS ALL
$ COSP ALL
$ PRINT $ PUNCH INPUT 9 FILE 1
CHAN ALL TAPE RECOGX RUN NUMBER 1 FLIGHT LINE AITRCC DATE SEPTEMBER 2,1976
TIME 14.30 ALTITUDE 999999 FEET GROUND HEADING 180 DEGREES
FIEL SWP1 1 LINE 456,464,1 COLU 470,473,1
FIEL SWP1 2 LINE 463,465,1 COLU 464,476,1
FIEL SWP1 3 LINE 559,565,1 COLU 475,481,1
FIEL SWP2 1 LINE 445,451,1 COLU 387,393,1
FIEL ROAD 1 LINE 469,473,1 COLU 466,467,1
FIEL ROAD 2 LINE 485,489,1 COLU 464,465,1
FIEL WTR1 1 LINE 445,448,1 COLU 439,443,1
FIEL WTR1 2 LINE 445,448,1 COLU 465,480,1
FIEL WTR1 3 LINE 450,453,1 COLU 447,459,1
FIEL WTR1 4 LINE 455,467,1 COLU 489,491,1
FIEL WTR1 5 LINE 489,498,1 COLU 430,433,1
FIEL WTR2 1 LINE 480,481,1 COLU 452,478,1
FIEL WTR2 2 LINE 505,507,1 COLU 409,421,1
FIEL WTR2 3 LINE 508,509,1 COLU 403,422,1
FIEL WTR2 4 LINE 511,513,1 COLU 399,414,1
FIEL WTR3 1 LINE 521,565,1 COLU 387,402,1
FIEL MON1 1 LINE 474,479,1 COLU 426,435,1
FIEL MON1 2 LINE 485,497,1 COLU 406,413,1
FIEL MON1 3 LINE 485,500,1 COLU 436,448,1
$ BEGIN

                    CONTROL CARD ERROR DIAGNOSTICS

**********   NO FATAL ERRORS ENCOUNTERED - - - BEGIN EXECUTION   ***********
```

Figure 7: PHASE II CONTROL CARD. With the RECOG coordinates of the rectangulars shown in Figure 3 and 4, swamp areas; road; estuary and detaic area of Bang Pakong; and the mangrove forestry have been selected as training sets for which statistics are to be obtained. A mean vector and covariance matrix, a coincident spectral plot, class spectral plots, and class histograms for each channel are to be obtains.

REMOTE SENSING DATA ANALYSIS

PHASE TWO

RUN NUMBER 1 FLIGHT DATE SEPTEMBER 2

FLIGHT LINE AITRCC FLIGHT TIME 14.30

TAPE NUMBER RECOGX FLIGHT ALTITUDE999999 FEET

FILE NUMBER 1 GROUND HEADING 180 DEGREES

4 CHANNELS 824 POINTS PER SCAN LINE

CLASS NAME	FIELD NUMBER	LINES			COLUMNS		
MON1	1	474	479	1	426	435	1
MON1	2	485	497	1	406	413	1
MON1	3	485	500	1	436	448	1
ROAD	1	469	473	1	466	467	1
ROAD	2	485	489	1	464	465	1
SWP1	1	456	464	1	470	473	1
SWP1	2	463	465	1	464	476	1
SWP1	3	559	565	1	475	481	1
SWP2	1	445	451	1	387	393	1
WTR1	1	445	448	1	439	443	1
WTR1	2	445	448	1	465	480	1
WTR1	3	450	453	1	447	459	1
WTR1	4	455	467	1	489	491	1
WTR1	5	489	498	1	430	433	1
WTR2	1	480	481	1	452	478	1
WTR2	2	505	507	1	409	421	1
WTR2	3	508	509	1	403	422	1
WTR2	4	511	513	1	399	414	1
WTR3	1	521	565	1	387	402	1

Figure 8: PHASE II CONTROL CARD SUMMARY OUTPUT. Given training classes and their RECOG coordinates, PHASE II first sorted the control cards correspending to the alphabetical order and then listed them out as a summary output.

CORRELATION MATRIX

CLASS MON1

1.00											
0.49	1.00										
0.09	-0.04	1.00									
0.05	-0.16	0.87	1.00								
0.0	0.0	0.0	0.0	0.0							
0.0	0.0	0.0	0.0	0.0	0.0						
0.0	0.0	0.0	0.0	0.0	0.0	0.0					
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

AND THE MEAN VECTOR . . .

21.77	12.78	35.91	20.24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

THE STANDARD DEVIATIONS .

1.21	0.89	3.69	2.46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CORRELATION MATRIX

CLASS ROAD

1.00											
0.69	1.00										
0.03	-0.08	1.00									
-0.05	-0.19	0.92	1.00								
0.0	0.0	0.0	0.0	0.0							
0.0	0.0	0.0	0.0	0.0	0.0						
0.0	0.0	0.0	0.0	0.0	0.0	0.0					
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

AND THE MEAN VECTOR . . .

29.05	23.95	35.25	17.50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

THE STANDARD DEVIATIONS .

2.04	2.62	3.55	2.31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CORRELATION MATRIX

CLASS SWP1

1.00											
0.64	1.00										
0.14	0.35	1.00									
0.12	0.28	0.93	1.00								
0.0	0.0	0.0	0.0	0.0							
0.0	0.0	0.0	0.0	0.0	0.0						
0.0	0.0	0.0	0.0	0.0	0.0	0.0					
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

AND THE MEAN VECTOR . . .

25.64	19.05	18.72	5.98	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

THE STANDARD DEVIATIONS .

1.52	2.42	3.60	2.64	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 9: PHASE II CORRELATION MATRICES. The correlation matrices, mean vectors, and standard deviation vectors are given for three of the seven classes requested. Only the lower triangular portions of the symmetric correlation matrices are printed.

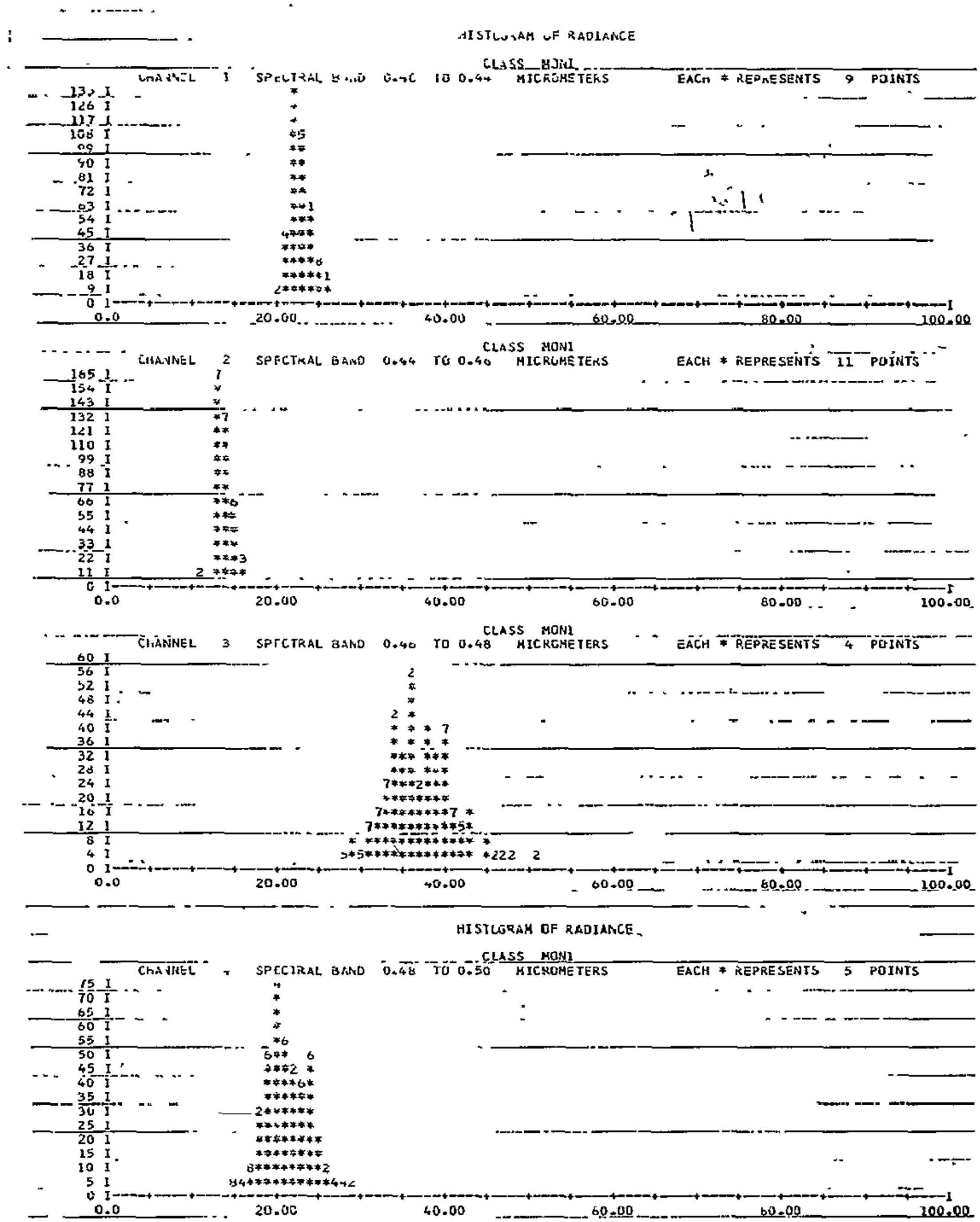


Figure 10a: Class histograms for mangrove training class

Figure 10: PHASE II CLASS HISTOGRAMS. The histograms for the selected training classes at mangrove forestry area around Bang Pakong estuary in channel 1 to 4 (Band 4 to 7 according to LANDSAT–1 and –2 MSS band):

Figure 10a: class histograms for mangrove training class.
Figure 10b: class histograms for road training class
Figure 10c: class histograms for swamp and shallow water level class.

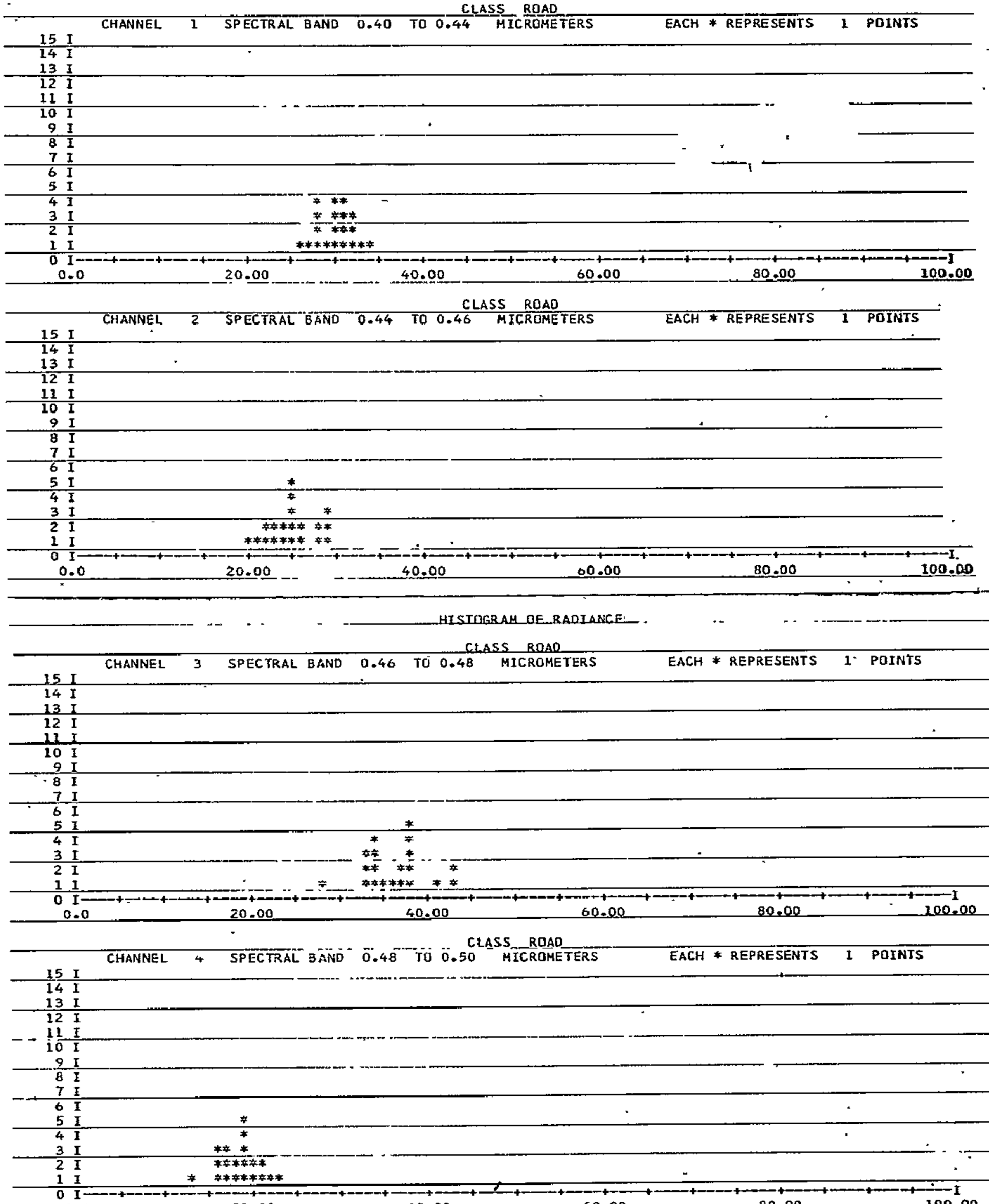


Figure 10b: Class histograms for road training class.

```
                                        CLASS  SWP1
      CHANNEL  1   SPECTRAL BAND  0.40  TO 0.44   MICROMETERS        EACH * REPRESENTS   3  POINTS
 45 I
 42 I
 39 I                             *
 36 I                             *
 33 I                            6*
 30 I                            **
 27 I                            **
 24 I                           6**
 21 I                           ***
 18 I                          ****
 15 I                          ****
 12 I                          ****
  9 I                          ****
  6 I                         6****
  3 I                       3 *****6*   3
  0 I----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----I
   0.0                20.00               40.00               60.00               80.00              100.00
```

HISTOGRAM OF RADIANCE

```
                                        CLASS  SWP1
      CHANNEL  2   SPECTRAL BAND  0.44  TO 0.46   MICROMETERS        EACH * REPRESENTS   2  POINTS
 30 I
 28 I
 26 I                     *
 24 I                  * *
 22 I                  * *
 20 I                  * *
 18 I                  ***
 16 I                  ***
 14 I                  ***5  5
 12 I                  ***** *
 10 I                  ***** *
  8 I                 ****** *
  6 I                5****** *
  4 I                ******* *
  2 I                **********     5
  0 I----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----I
   0.0                20.00               40.00               60.00               80.00              100.00
```

```
                                        CLASS  SWP1
      CHANNEL  3   SPECTRAL BAND  0.46  TO 0.48   MICROMETERS        EACH * REPRESENTS   2  POINTS
 30 I
 28 I
 26 I
 24 I
 22 I
 20 I                  5
 18 I                5 *
 16 I                * *
 14 I                * **
 12 I               ** **
 10 I               ** **
  8 I               **5******
  6 I               **********5* 5
  4 I               *********** *
  2 I              *************5* *55
  0 I----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----I
   0.0                20.00               40.00               60.00               80.00              100.00
```

```
                                        CLASS  SWP1
      CHANNEL  4   SPECTRAL BAND  0.48  TO 0.50   MICROMETERS        EACH * REPRESENTS   2  POINTS
 30 I     *
 28 I     *
 26 I     *5
 24 I     **
 22 I     **
 20 I     **
 18 I     **
 16 I     **
 14 I    ***5
 12 I    *****
 10 I    *****
  8 I    ******5
  6 I    *******  5
  4 I    *******5*
  2 I   5************
  0 I----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----I
   0.0                20.00               40.00               60.00               80.00              100.00
```

Figure 10c: Class histograms for swamp and shallow water level class.

```
                                  REMOTE SENSING DATA ANALYSIS

                                           PHASE  TWO

                                      CLASS SPECTRAL PLOTS

                              ( MEAN PLUS AND MINUS ONE STD. DEV. )

                 CLASS ... MUNI                  TOTAL NUMBER OF SAMPLE POINTS ...  372

SPECTRAL        0.0                20.00               40.00               60.00               80.00               100.
    BANDS        I---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---I
  MICROMETERS    I
                 I
                 I
 0.40 - 0.44     I                    ***
                 I
                 I
 0.44 - 0.46     I            ***
                 I
                 I
 0.46 - 0.48     I                               *********
                 I
                 I
 0.48 - 0.50     I                  ******
                 I
                 I
                 I---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---I
                0.0                20.00               40.00               60.00               80.00               100.00
```

```
                                  REMOTE SENSING DATA ANALYSIS

                                           PHASE  TWO

                                      CLASS SPECTRAL PLOTS

                              ( MEAN PLUS AND MINUS ONE STD. DEV. )

                 CLASS ... ROAD                  TOTAL NUMBER OF SAMPLE POINTS ...  20

SPECTRAL        0.0                20.00               40.00               60.00               80.00               100.
    BANDS        I---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---I
  MICROMETERS    I
                 I
                 I
 0.40 - 0.44     I                           *****
                 I
                 I
 0.44 - 0.46     I                     *******
                 I
                 I
 0.46 - 0.48     I                                ********
                 I
                 I
 0.48 - 0.50     I               ******
                 I
                 I
                 I---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---I
                0.0                20.00               40.00               60.00               80.00               100.00
```

```
                                  REMOTE SENSING DATA ANALYSIS

                                           PHASE  TWO

                                      CLASS SPECTRAL PLOTS

                              ( MEAN PLUS AND MINUS ONE STD. DEV. )

                 CLASS ... SHPI                  TOTAL NUMBER OF SAMPLE POINTS ...  124

SPECTRAL        0.0                20.00               40.00               60.00               80.00               100.
    BANDS        I---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---I
  MICROMETERS    I
                 I
                 I
 0.40 - 0.44     I                        ****
                 I
                 I
 0.44 - 0.46     I                 *****
                 I
                 I
 0.46 - 0.48     I               *********
                 I
                 I
 0.48 - 0.50     I   *******
                 I
                 I
                 I---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---I
                0.0                20.00               40.00               60.00               80.00               100.00
```

Figure 11: PHASE II CLASS SPECTRAL PLOTS. The class spectral plots for the three classes of Mangrove forestry, and swamp area indicating the statistical variation in gray tone for each channel are given. The center of the row of asterisks is the mean value and the length of the row represents plus and minus one standard deviation.

REMOTE SENSING DATA ANALYSIS

PHASE TWO

COINCIDENT CLASS SPECTRAL PLOT

(MEAN PLUS AND MINUS ONE STD. DEV.)

LEGEND

A = CLASS	1	MON1
B = CLASS	2	ROAD
C = CLASS	3	SWP1
D = CLASS	4	SWP2
E = CLASS	5	WTR1
F = CLASS	6	WTR2
G = CLASS	7	WTR3

```
   SPECTRAL     0.0                20.00               40.00               60.00               80.00              100.00
    BANDS       I---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---I
 MICROMETERS    I                                                                                                    I
                I                                                                                                    I
                I                                                                                                    I
                I                     *A*                                                                            I
                I                           **B**                                                                    I
                I                        **C*                                                                        I
 0.40  - 0.44   I                   **D*                                                                             I
                I                           *E*                                                                      I
                I                         **F*                                                                       I
                I                         *G*                                                                        I
                I                                                                                                    I
                I                                                                                                    I
                I            *A*                                                                                     I
                I                     ***B***                                                                        I
                I                 **C**                                                                              I
 0.44  - 0.46   I            *D*                                                                                     I
                I                   *E**                                                                             I
                I              **F**                                                                                 I
                I             *G*                                                                                    I
                I                                                                                                    I
                I                                                                                                    I
                I                                ****A****                                                           I
                I                                ***B****                                                            I
                I               ****C****                                                                            I
 0.46  - 0.48   I              ***D***                                                                               I
                I         **E**                                                                                      I
                I      **F**                                                                                         I
                I     *G**                                                                                           I
                I                                                                                                    I
                I                                                                                                    I
                I                  **A***                                                                            I
                I               ***B**                                                                               I
                I   ***C***                                                                                          I
 0.48  - 0.50   I      **D**                                                                                         I
                I*E*                                                                                                 I
                IF*                                                                                                  I
                IG                                                                                                   I
                I                                                                                                    I
                I                                                                                                    I
                I---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---I
               0.0                 20.00               40.00               60.00               80.00              100.00
```

Figure 12: PHASE II COINCIDENT SPECTRAL PLOT. All seven class spectral plots have been plotted on one axis for interclass comparison.

```
                    REMOTE SENSING DATA ANALYSIS

                           PHASE THREE

$$$$$$$$$$$$$$$$$$$$$   GROUP OF CONTROL CARDS ENCOUNTERED   $$$$$$$$$$$$$$$$$$$$$

COVARIANCE MON1
MEAN MON1
COVARIANCE ROAD
MEAN ROAD
COVARIANCE SWP1
MEAN SWP1
COVARIANCE SWP2
MEAN SWP2
COVARIANCE WTR1
MEAN WTR1
COVARIANCE WTR2
MEAN WTR2
COVARIANCE WTR3
MEAN WTR3
NCHA 4
BEST 2

                  CONTROL CARD ERROR DIAGNOSTICS

**********     NO FATAL ERRORS ENCOUNTERED      BEGIN EXECUTION     ***********
```

Figure 13: PHASE III CONTROL CARDS. Class mean vectors and covariance matrices request for the selection of the best two out of four channels.

```
LEGENDO
        CLASS     SYMBOL
        MON1        A
        ROAD        B
        SWP1        C
        SWP2        D
        WTR1        E
        WTR2        F
        WTR3        G
CHANNELS                MIN       MAX      AVERAGE

3 4                     4.8     2044.8    277.2AB =   10.7AC =   67.8AD =   86.3AE =  228.6AF =  407.2
                                              AG = 2044.8BC =   44.6BD =   62.1BE =  176.2BF =  311.8
                                              BG = 1690.5CD =    8.5CE =   17.2CF =   44.3CG =  265.4
                                              DE =   21.3DF =   40.6DG =  245.5EF =    4.8EG =   34.5
                                              FG =    8.9
2 4                    12.7     1334.8    252.7AB =  181.8AC =  126.9AD =  124.5AE =  310.6AF =  627.1
                                              AG = 1334.8BC =   53.1BD =  144.2BE =  178.8BF =  359.9
                                              BG = 1083.1CD =   62.2CE =   15.3CF =   33.6CG =  146.4
                                              DE =  149.7DF =  109.2DG =  159.0EF =   12.7EG =   80.3
                                              FG =   13.6
2 3                    12.6      905.9    214.2AB =  181.0AC =  114.5AD =   83.6AE =  280.0AF =  603.1
                                              AG =  644.6BC =   46.5BD =  142.3BE =  150.5BF =  349.4
                                              BG =  905.9CD =   46.4CE =   20.2CF =   54.3CG =  181.9
                                              DE =  123.5DF =  117.1DG =  135.7EF =   12.6EG =   90.3
                                              FG =   15.6
1 4                     3.8     1326.8    217.8AB =   53.4AC =   89.4AD =  103.4AE =  282.2AF =  437.5
                                              AG = 1326.8BC =   50.1BD =   82.9BE =  177.7BF =  311.3
                                              BG =  999.9CD =   31.5CE =   20.9CF =   30.2CG =  114.0
                                              DE =  128.5DF =  108.9DG =  193.9EF =    6.5EG =   21.3
                                              FG =    3.8
1 3                     7.2      862.6    172.3AB =   50.9AC =   67.8AD =   73.0AE =  223.0AF =  298.4
                                              AG =  845.6BC =   45.4BD =   84.7BE =  147.9BF =  240.3
                                              BG =  862.6CD =   24.8CE =   24.3CF =   38.4CG =  157.5
                                              DE =  113.5DF =   99.4DG =  164.7EF =    6.2EG =   41.0
                                              FG =    7.2
1 2                     1.9      182.1     55.1AB =  182.1AC =   63.5AD =    1.9AE =  127.8AF =   42.7
                                              AG =   24.5BC =    9.3BD =  111.5BE =    9.0BF =   27.2
                                              BG =  162.1CD =   41.0CE =    9.6CF =    8.3CG =   53.7
                                              DE =  105.0DF =   43.4DG =   32.4EF =   12.4EG =   77.1
```

Figure 14: PHASE III SAMPLE OUTPUT. Given class mean vectors and covariance matrices, PHASE III computed the divergence between all pairs of classes as a function of channels. The best two out of 4 LANDSAT channels are to be selected for discriminating between seven given classes.

```
$$$$$$$$$$$$$$$$$$$$$$   GROUP OF CONTROL CARDS ENCOUNTERED   $$$$$$$$$$$$$$$$$$$$$$

$ LEVELS
$ DISPLAY
FILE 1 INPUT 9 CHAN 2 4
FIEL DP01 1 LINE 837,889,1 COLU 513,549,1
FIEL DP02 1 LINE 521,653,1 COLU 238,357,1
FIEL DP03 1 LINE 521,653,1 COLU 358,477,1
FIEL DP04 1 LINE 838,837,1 COLU 513,512,1
FIEL DP05 1 LINE 838,837,1 COLU 513,512,1
FIEL DP06 1 LINE 838,837,1 COLU 513,512,1
FIEL DP07 1 LINE 838,837,1 COLU 513,512,1
FIEL DP08 1 LINE 838,837,1 COLU 513,512,1
FIEL DP09 1 LINE 838,837,1 COLU 513,512,1
FIEL DP10 1 LINE 838,837,1 COLU 513,512,1
FIEL DP11 1 LINE 838,837,1 COLU 513,512,1
FIEL DP12 1 LINE 838,837,1 COLU 513,512,1
FIEL DP13 1 LINE 838,837,1 COLU 513,512,1
FIEL DP14 1 LINE 838,837,1 COLU 513,512,1
FIEL DP15 1 LINE 838,837,1 COLU 513,512,1
MINI DP01 18.5 5.5 DP02 0 0 DP03 10.5 0 DP04 10.5 1.5 DP05 0 2.5
MINI DP06 9.5 2.5 DP07 10.5 2.5 DP08 11.5 2.5 DP09 13.5 0 DP10 13.5 1.5
MINI DP11 13.5 2.5 DP12 14.5 0 DP13 14.5 1.5 DP14 14.5 2.5 DP15 15.5 0
MAXI DP01 60 35 DP02 10 2 DP03 13 1 DP04 13 2 DP05 9 5
MAXI DP06 10 5 DP07 11 5 DP08 13 5 DP09 14 1 DP10 14 2
MAXI DP11 14 5 DP12 15 1 DP13 15 2 DP14 15 5 DP15 18 5
$ BEGIN
```

Figure 15: PHASE IV LEVELS CONTROL CARDS. A level-slicing classification with the indicated statistical maximum and minimum gray tone values in channel 2 and 4 (Bands 5 and 7) has been requested.

CONTROL CARD ERROR DIAGNOSTICS

********** NO FATAL ERRORS ENCOUNTERED - - - BEGIN EXECUTION **********

REMOTE SENSING DATA ANALYSIS

PHASE FOUR

FILE 1 7 CHANNELS 824 POINTS PER SCAN LINE

CLASS NAME	FIELD NUMBER	SYMBOL	LINES			COLUMNS		
DP01	1	A	837	889	1	513	549	1
DP02	1	B	521	653	1	238	357	1
DP03	1	C	521	653	1	358	477	1
DP04	1	D	838	837	1	513	512	1
DP05	1	E	838	837	1	513	512	1
DP06	1	F	838	837	1	513	512	1
DP07	1	G	838	837	1	513	512	1
DP08	1	H	838	837	1	513	512	1
DP09	1	I	838	837	1	513	512	1
DP10	1	J	838	837	1	513	512	1
DP11	1	K	838	837	1	513	512	1
DP12	1	L	838	837	1	513	512	1
DP13	1	M	838	837	1	513	512	1
DP14	1	N	838	837	1	513	512	1
DP15	1	O	838	837	1	513	512	1

Figure 16: PHASE IV LEVELS SORTED CONTROL CARD SUMMARY. A sorted list of the test fields employed in the classification is given. The symbol to be used for each class in the recognition map is given.

```
            5555555555555555555555555555555555555
            1111111222222222223333333333444444444
            3456789012345678901234567890123456789

    837     AA  AAAAA   AAAAAAAAAAAAAAAAAAAAAA AA
    838     AAA  AAA   AAAA A  AAAAAAAAAAAAA   AA
    839     AAAAAAAAAAAAAAA    AAAAAAAAAAAAAAAAAA
    840     AAAAAAAAA AAAA  AAAAAAAAAAAAAAAAAAAAA
    841     AAAAAAAA AA          AAAAAAAAAAAAA AA
    842     AAAAAAA  A             AAA AAAAAAAAAA
    843     AAA AAAAA           A  AAAAAAAAAAAAAA
    844     AA  AAAAAHGGF               AAAAAAAAA
    845     AA  AAA BDCBDB              AAAAAAAAA
    846     AAAAAAAABBBBBBBF   A        AAAA A
    847     AAAAAAABDDCBDFBBG            AAAA
    848      AAAAACBCCBBCBBBB      G        AAAA
    849     AAA  BBCBCCCCCBCDDBH HBG       AAAAA
    850     A DCCDBCCDDBBCBBCBBBBBB            AA
    851     AHCBCCCCCCCBCCBCBBCBBD             AA
    852     AABBDCBBBBBBBBBBBBBBBBBFEE          A
    853     AADBBCCDBCCBBBBBBBBBBBBGFDGF     A
    854     AACBCBBCBBCCCBBBBBBBBEEEEBBBG       A
    855     AACCBBBBBCBBBBBBBBBBBBDBBBBBBE      A
    856     AABCBBCCCBBCBBBBBBBBBBBCBBBBBBF
    857     AOBCBCCBCBBBBBBCCBBBCBBBBCCBBD    AAA
    858     AAHBBBBBBBBBBBBBBBBBBBBBBBBBBBBB  AAA
    859      AHCCCCBBBBBBBBBBBBBBBBBBBBBBBB   AAA
    860     AAHCCBBBBBBBBBBBBBBBBBBBBBBBBBB   AAA
    861     AAHBCCBBBBBBBBBBBBBBBCBBBBBBBBE  AAAA
    862     AACBBBBBBBBBBBBBBBBBBBBBBBBBBBBB  AAA
    863     AACBCCCBCBBBBBBBBBBBBBBBBBBCBBBBB   A
    864     AAABBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBE F
    865     AAABBDBCBBBBBBBBBBBBBBBCBBBBBBBBDBBBBB
    866      AA BBBBBBBBBBBBBBBBBBBBBBBBBBG   EBBB
    867         BBBBBBBBBBBBBBBBBBBBBBBBBBB     GG
    868       A  CBBBBBBBBBBBBBBBBBBBBBBBB      AA
    869     AAAA BBBBBBBCBBBBBBBBBBBBBBBBG   AAAAA
    870     AAA FBBBBBBBBBBBBBBBBBBBBBBBEE   AAAAA
    871     AA BBBBBBBCBBBBBBBBBBBBBBFFDF    AAAAA
    872     AA BBBBBBBBBBBBBBBBBBBBBBBBEGEBE AAAAA
    873     AA BBBBBBBBBBBBBBBBBBBBBBBBEEBB   AAAA
    874     AAHBBBBBBBBBBBBBBBBBBBBBEH  EE     AAA
    875     AA BBBBBBBCBBBBBBBBBBBB             AA
    876     AAA BBBBBBBBBBBBBBBBEBBBBF  A        A
    877     AA FBBBBBBBBCBBBBCFBDBF    AA A     AA
    878     A  BBBBBBBBBBBBBBBBBBBB        AA
    879         G  GBBBBBBBBBBGBBBG      AAAAAAAA
    880     AAAA A    GBBBBBBEBBBBEE     AAAAAAAA
    881     AAAAAAAA    GGGDBBDBCBBE    AAAAAAAAA
    882     AAAAAAAAA      FFBBBBBE      AAAAAAAA
    883     AAAAAAAAAAA      GFBDBF        AAAAAA
    884     AAAAAAAA AAA      EBBBF         AAAAA
    885     AAAAAAAAAAAAA       GGG    AAAAAAAAAA
    886     AAAAA AA AAAA             AAAAAAAAAAA
    887     AAAAAAAA     AAAA AAAA     AAAAAAAAAA
    888     AAAAAAAAAAAAAAAAAAAAAAA      AAAAAAAA
    889     AAAAAAAAAAAAAAAAAAAAAAA      AAAAAAAA
```

Figure 17: PHASE IV LEVELS RECOGNITION MAP FOR BANG PRA RESERVOIR. The alphabetical symbols in the recognition map corresponds to numbers of statistical maximum and minimum gray tone values requested.

CLASSIFICATION SUMMARY

NUMBER OF YES POINTERS FOR EACH CLASS WITHIN EACH FIELD AND PERCENTAGES

FIELD	CLASS	NUMBER	PER CENT
1	DP01	611	31.2
1	DP02	674	34.4
1	DP03	87	4.4
1	DP04	25	1.3
1	DP05	27	1.4
1	DP06	21	1.1
1	DP07	25	1.3
1	DP08	10	0.5
1	DP09	0	0.0
1	DP10	0	0.0
1	DP11	0	0.0
1	DP12	0	0.0
1	DP13	0	0.0
1	DP14	0	0.0
1	DP15	1	0.1
FIELD TOTAL		1961	

Figure 18: PHASE IV LEVELS CLASSIFICATION SUMMARY. Individual field results as well as the overall class summary are given. Note numbers of points indicated in the summary can be thought of as number of acreage for the LANDSAT –1 and –2 MSS data.

```
$$$$$$$$$$$$$$$$$$$$   GROUP OF CONTROL CARDS ENCOUNTERED   $$$$$$$$$$$$$$$$$$$$

$ EUCLID
$ DISPLAY
THRE MON1 1 WTR1 1 WTR2 1 WTR3 1 SWP1 1 SWP2 1 ROAD 1
FILE 1 INPUT 9 CHAN 2 4
                    COVARIANCE MATRIX   CLASS   MON1
MEAN MON1
                    COVARIANCE MATRIX   CLASS   WTR1
MEAN WTR1
                    COVARIANCE MATRIX   CLASS   WTR2
MEAN WTR2
                    COVARIANCE MATRIX   CLASS   WTR3
MEAN WTR3
                    COVARIANCE MATRIX   CLASS   SWP1
MEAN SWP1
                    COVARIANCE MATRIX   CLASS   SWP2
MEAN SWP2
                    COVARIANCE MATRIX   CLASS   ROAD
MEAN ROAD
FIEL MON1 1 LINE 445,565,1 COLU 387,506,1
FIEL WTR1 1 LINE 445,444,1 COLU 387,506,1
FIEL WTR2 1 LINE 445,444,1 COLU 387,506,1
FIEL WTR3 1 LINE 445,444,1 COLU 387,506,1
FIEL SWP1 1 LINE 445,444,1 COLU 387,506,1
FIEL SWP2 1 LINE 445,444,1 COLU 387,506,1
FIEL ROAD 1 LINE 445,444,1 COLU 387,506,1
$ BEGIN
```

Figure 19: PHASE IV EUCLID CONTROL CARDS. An Euclidean Distance classification of the seven defined classes indicated sets using channel 2, 4, and the threshold value of 1 for each class has been requested.

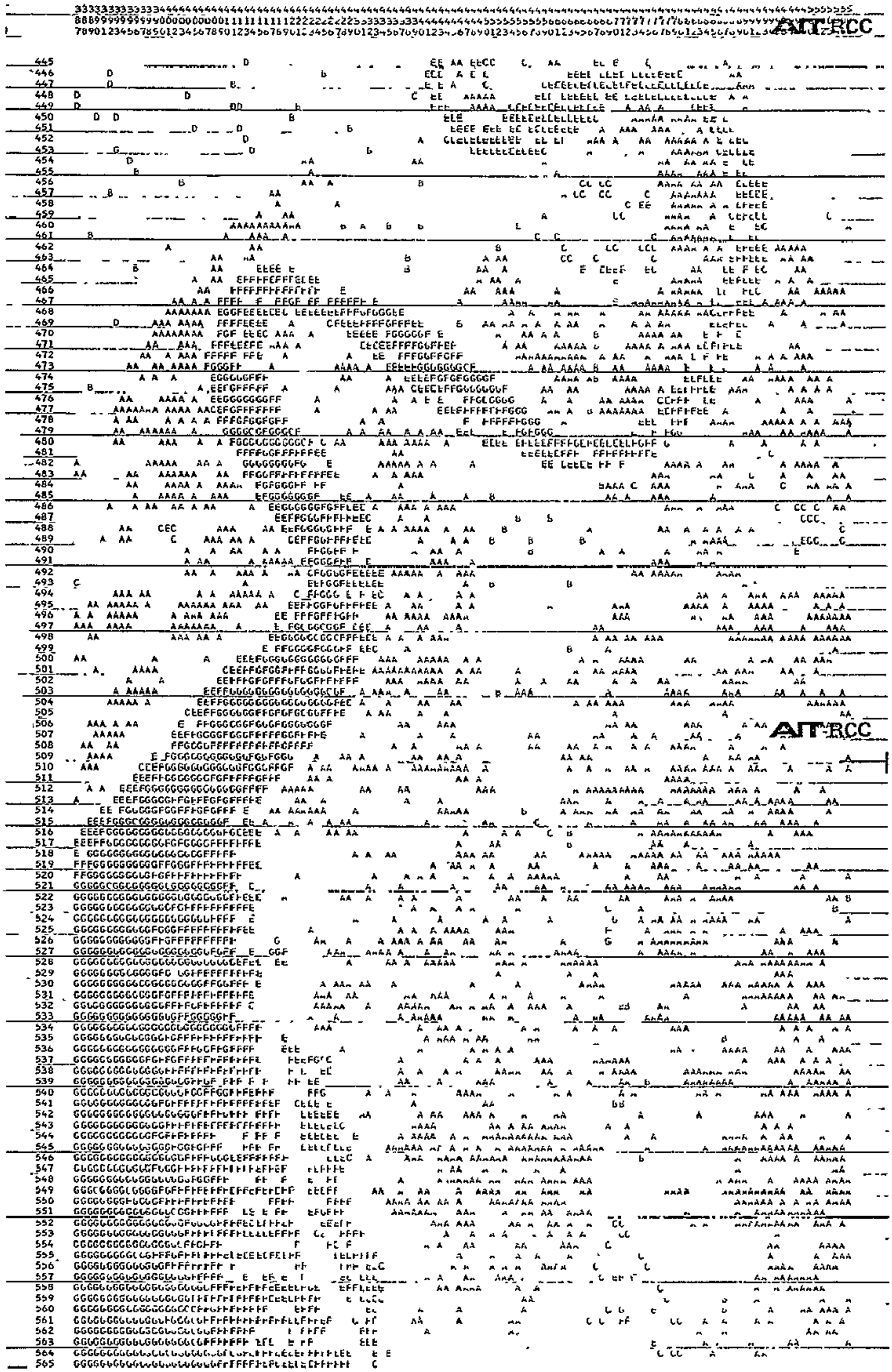


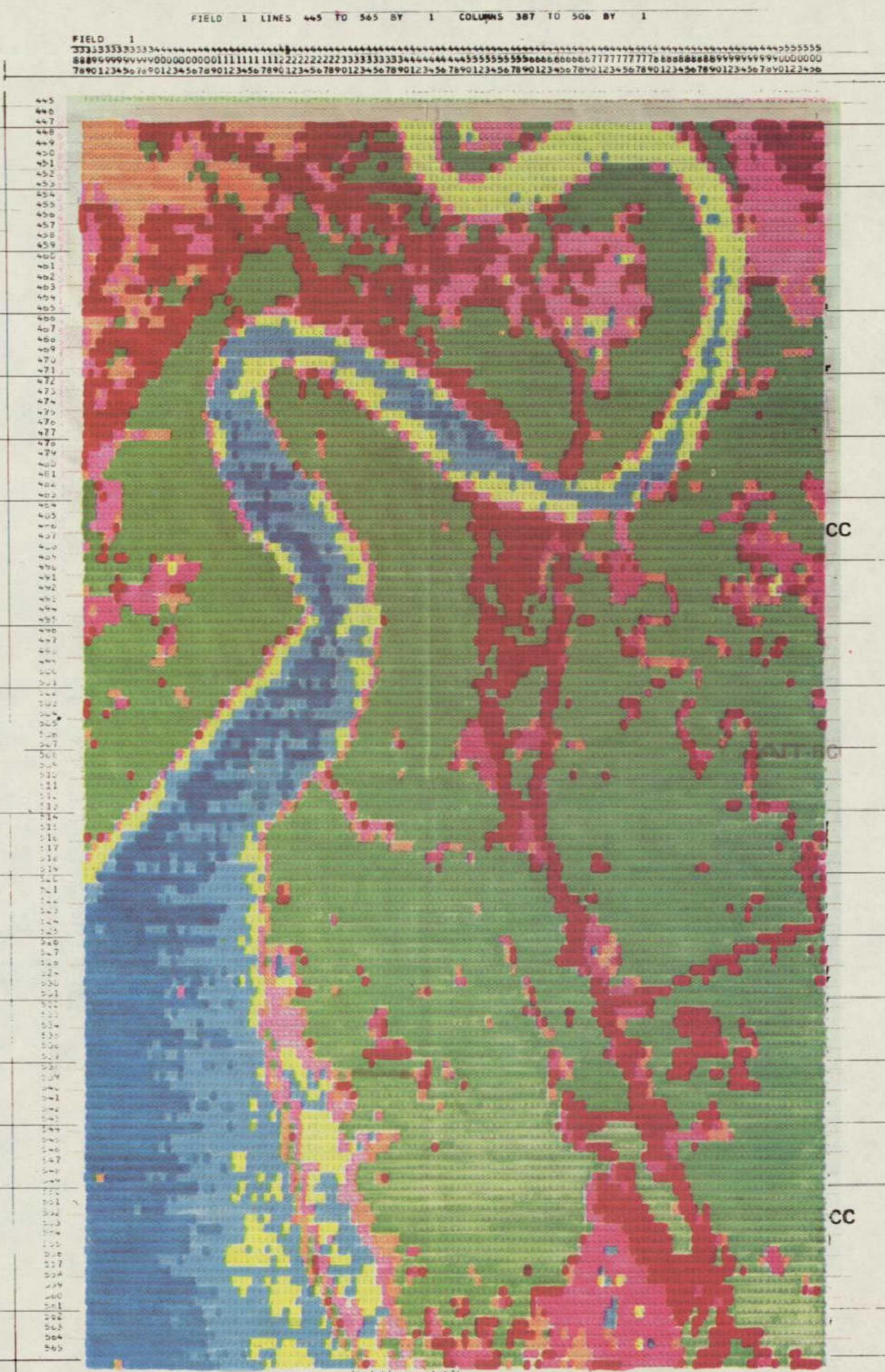
Figure 20: PHASE IV EUCLID RECOGNITION MAP FOR THE MANGROVE AREA AROUND THE BANG PAKONG ESTUARY. The alphabetical symbols in the recognition map correspond to the sequence of the statistical training sets have been read.

REMOTE SENSING DATA ANALYSIS

PHASE FOUR

```
$$$$$$$$$$$$$$$$$$$$   GROUP OF CONTROL CARDS ENCOUNTERED   $$$$$$$$$$$$$$$$$$$$
$ GLIKE
$ DISPLAY
FILE 1 INPUT 9 CHAN 2 4
COVARIANCE MON1
MEAN MON1
COVARIANCE ROAD
MEAN ROAD
COVARIANCE SWP1
MEAN SWP1
COVARIANCE SWP2
MEAN SWP2
COVARIANCE WTR1
MEAN WTR1
COVARIANCE WTR2
MEAN WTR2
COVARIANCE WTR3
MEAN WTR3
FIEL MON1 1 LINE 445,565,1 COLU 387,506,1
FIEL ROAD 1 LINE 445,444,1 COLU 387,506,1
FIEL SWP1 1 LINE 445,444,1 COLU 387,506,1
FIEL SWP2 1 LINE 445,444,1 COLU 387,506,1
FIEL WTR1 1 LINE 445,444,1 COLU 387,506,1
FIEL WTR2 1 LINE 445,444,1 COLU 387,506,1
FIEL WTR3 1 LINE 445,444,1 COLU 387,506,1
$ BEGIN
```

Figure 21: PHASE IV GLIKE CONTROL CARDS. A Gaussian maximal likelihood classification of the seven indicated statistical sets using channel 2 and 4 .



TEST FIELD RESULTS

FIELD	CLASS	SYMBOL	THRESHOLD	NUMBER OF POINTS	PERCENT
1	[illegible]	[illegible]	7.024	[illegible]	[illegible]
	[illegible]	B	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	SWP2	D	[illegible]	[illegible]	[illegible]
	WTR1	E	13.615	801	5.52
	WTR2	F	13.615	[illegible]	[illegible]
	WTR3	G	13.615	1202	[illegible]

TOTAL NUMBER OF POINTS = 14520

Figure 22: PHASE IV GLIKE RECOGNITION MAP FOR THE MANGROVE AREA AROUND THE BANG PAKONG ESTUARY. The alphabetical symbols in the recognition map were assigned to every pixel because of the conditional probability assumption.

```
REMOTE SENSING DATA ANALYSIS

PHASE FIVE

$$$$$$$$$$$$$$$$$$$$   GROUP OF CONTROL CARDS ENCOUNTERED   $$$$$$$$$$$$$$$$$$$$$

FILE 1 INPUT 9 CHAN 2 4

FIEL LINE 445,565,1 COLU 387,506,1

CLAS MON1 A ROAD B SWP1 C SWP2 D WTR1 E WTR2 F WTR3 G

COVARIANCE MON1

MEAN MON1

COVARIANCE ROAD

MEAN ROAD

COVARIANCE SWP1

MEAN SWP1

COVARIANCE SWP2

MEAN SWP2

COVARIANCE WTR1

MEAN WTR1

COVARIANCE WTR2

MEAN WTR2

COVARIANCE WTR3

MEAN WTR3

$ BEGIN

CONTROL CARD ERROR DIAGNOSTICS

**********   NO FATAL ERRORS ENCOUNTERED - - - BEGIN EXECUTION   ***********

+++ FILE WRITTEN ON TAPE 8 +++
```

Figure 23: PHASE V CONTROL CARDS AND SAMPLE OUTPUT. A Gaussian maximal likelihood classification using channel 2 and 4 for the RECOGX coordinates: line 445 to 565 and its column 387 to 506. The assigned symbol associated with its conditional probability value in the recognition map is written into the computer file for future use in PHASE VI.

REMOTE SENSING DATA ANALYSIS

PHASE SIX

$$$$$$$$$$$$$$$$$$$$ GROUP OF CONTROL CARDS ENCOUNTERED $$$$$$$$$$$$$$$$$$$$

FILE 1 FIEL LINE 445,565,1 COLU 387,506,1

THRE 4,7,2,3,1,1,1

$ BEGIN

DESCRIPTION OF FILE 1 ON INPUT TAPE

CHANNELS USED IN PHASE FIVE CLASSIFICATIONO

CHANNEL 2 SPECTRAL BAND 0.60 TO 0.70 MICROMETERS

CHANNEL 4 SPECTRAL BAND 0.80 TO 1.10 MICROMETERS

LEGENDO

CLASS	SYMBOL	THRESHOLD VALUE
MON1	A	7.824
ROAD	B	4.605
SWP1	C	10.600
SWP2	D	9.210
WTR1	E	13.815
WTR2	F	13.815
WTR3	G	13.815

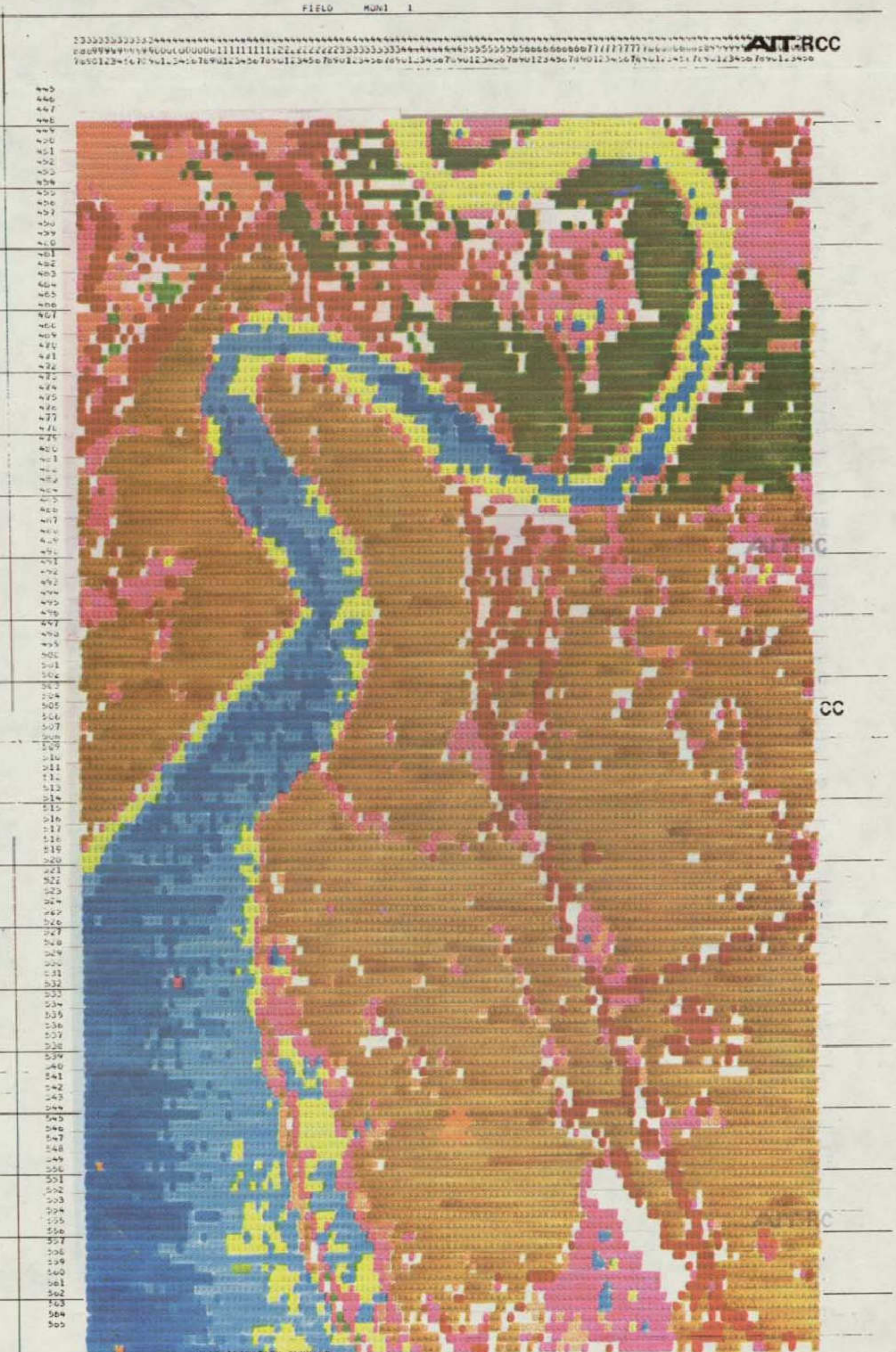
THIS FILE IS DESCRIBED BYO

LINES 445 TO 565 BY 1 AND

COLUMNS 387 TO 506 BY 1

DISPLAY THESE FIELDSO

Figure 24: PHASE VI CONTROL CARDS AND HEADER INFORMATION. Given the written file from PHASE V, the control cards request the recognition map at the RECOGX coordinates line 445 to 565 and column 387 to 506 and also request thresholding indices: 4– MON1, 7– ROAD, 2– SWP1, 3– SWP2, and 1 for WTR1, WTR2 and WTR3. For 2 channel classification, the thresholding indices 1, 2 and 3 correspond to Chi-square values 13.815 and 9.210 with are degree of freedom, respectively.



CLASSIFICATION SUMMARY

NUMBER OF YES POINTERS FOR EACH CLASS WITHIN EACH FIELD AND PERCENTAGES

AIT-RCC

FIELD	CLASS	NUMBER	PER CENT
1	HON1	7027	48.4
1	ROAD	2123	14.6
1	SWP1	1490	10.3
1	SWP2	579	4.0
1	WTR1	801	5.5
1	WTR2	1298	8.9
1	WTR3	1202	8.3
FIELD TOTAL		14520	

Figure 25: PHASE VI RECOGNITION MAP AND CLASSIFICATION SUMMARY. Compare this recognition map with Figure 22, the misclassification of road training set is eliminated because the sample points of low probability thresholded out is given.

REMOTE SENSING DATA ANALYSIS

PHASE SIX

$$$$$$$$$$$$$$$$$$$$$ GROUP OF CONTROL CARDS ENCOUNTERED $$$$$$$$$$$$$$$$$$$$$

```
FILE 1 FIEL LINE 445,565,1 COLU 387,506,1

CHAR MON1 M ROAD I WTR2 G

XCHA        W

THRE 4,9,4,4,4,4,4

$ BEGIN
```

DESCRIPTION OF FILE 1 ON INPUT TAPE

CHANNELS USED IN PHASE FIVE CLASSIFICATIONO

CHANNEL 2 SPECTRAL BAND 0.60 TO 0.70 MICROMETERS

CHANNEL 4 SPECTRAL BAND 0.80 TO 1.10 MICROMETERS

LEGENDO

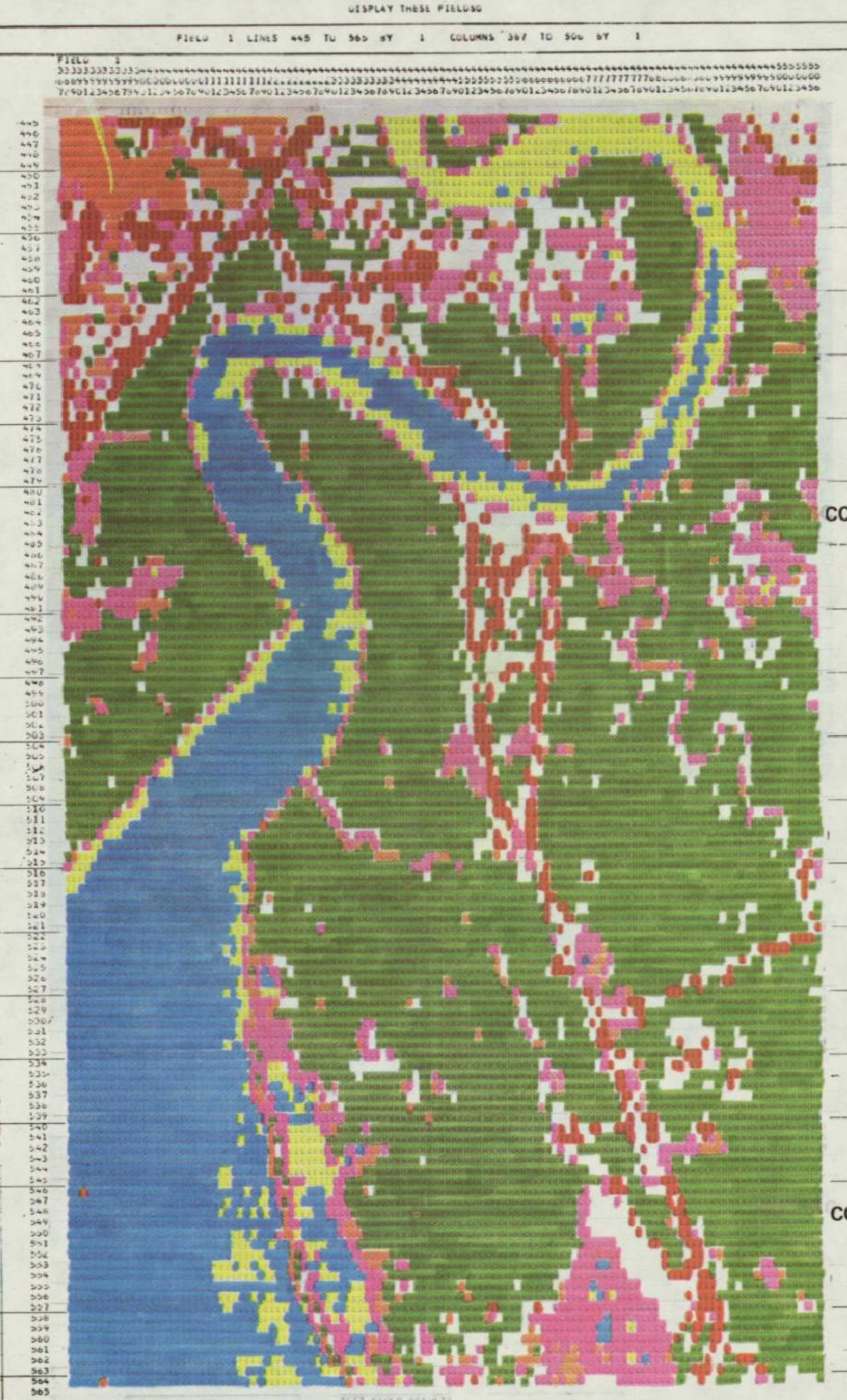
CLASS	SYMBOL	THRESHOLD VALUE
MON1	M	7.824
ROAD	I	2.770
SWP1	C	7.824
SWP2	D	7.824
WTR1	E	7.824
WTR2	G	7.824
WTR3	G	7.824

THIS FILE IS DESCRIBED BYO

LINES 445 TO 565 BY 1 AND

COLUMNS 387 TO 506 BY 1

Figure 26: PHASE VI CONTROL CARD AND HEADER INFORMATION. Given the same written file from PHASE V, control cards request to change the used alphabetical symbols in the recognition map.



TEST FIELD RESULTS

FIELD	CLASS	SYMBOL	THRESHOLD	NUMBER OF POINTS	PERCENT
1	MON1	M	7.824	6996	48.18
	ROAD	I	2.770	789	5.43
	SWP1	C	7.824	1488	10.25
	SWP2	D	7.824	579	3.99
	WTR1	E	7.824	801	5.52
	WTR2	F	7.824	1298	8.94
	WTR3	G	7.824	1202	8.28

TOTAL NUMBER OF POINTS = 14520

Figure 27: PHASE VI RECOGNITION MAP AND CLASSIFICATION SUMMARY. The ROAD boundaries in this recognition map are further eliminated because of the increased thresholding index.

REMOTE SENSING DATA ANALYSIS

PHASE ONE

G R A Y M A P

RUN NUMBER	1	DATE	AUGUST 23, 1976
FLIGHT LINE	AITRCC	TIME	11.00
TAPE NUMBER	ERTS5	ALTITUDE	9999 FEET
FILE NUMBER	1	GROUND HEADING	180 DEGREES

GRAYMAP OF CHANNEL 5 OF 7 CHANNELS

CHANNEL 5 SPECTRAL BAND 0.60 TO 0.70 MICROMETERS

THE CHARACTER SET USED FOR DISPLAY IS

FROM	0.0	TO	19.50	DISPLAYED &
FROM	19.50	TO	22.00	DISPLAYED W
FROM	22.00	TO	24.50	DISPLAYED V
FROM	24.50	TO	27.00	DISPLAYED
FROM	27.00	TO	30.00	DISPLAYED
FROM	30.00	TO	100.00	DISPLAYED

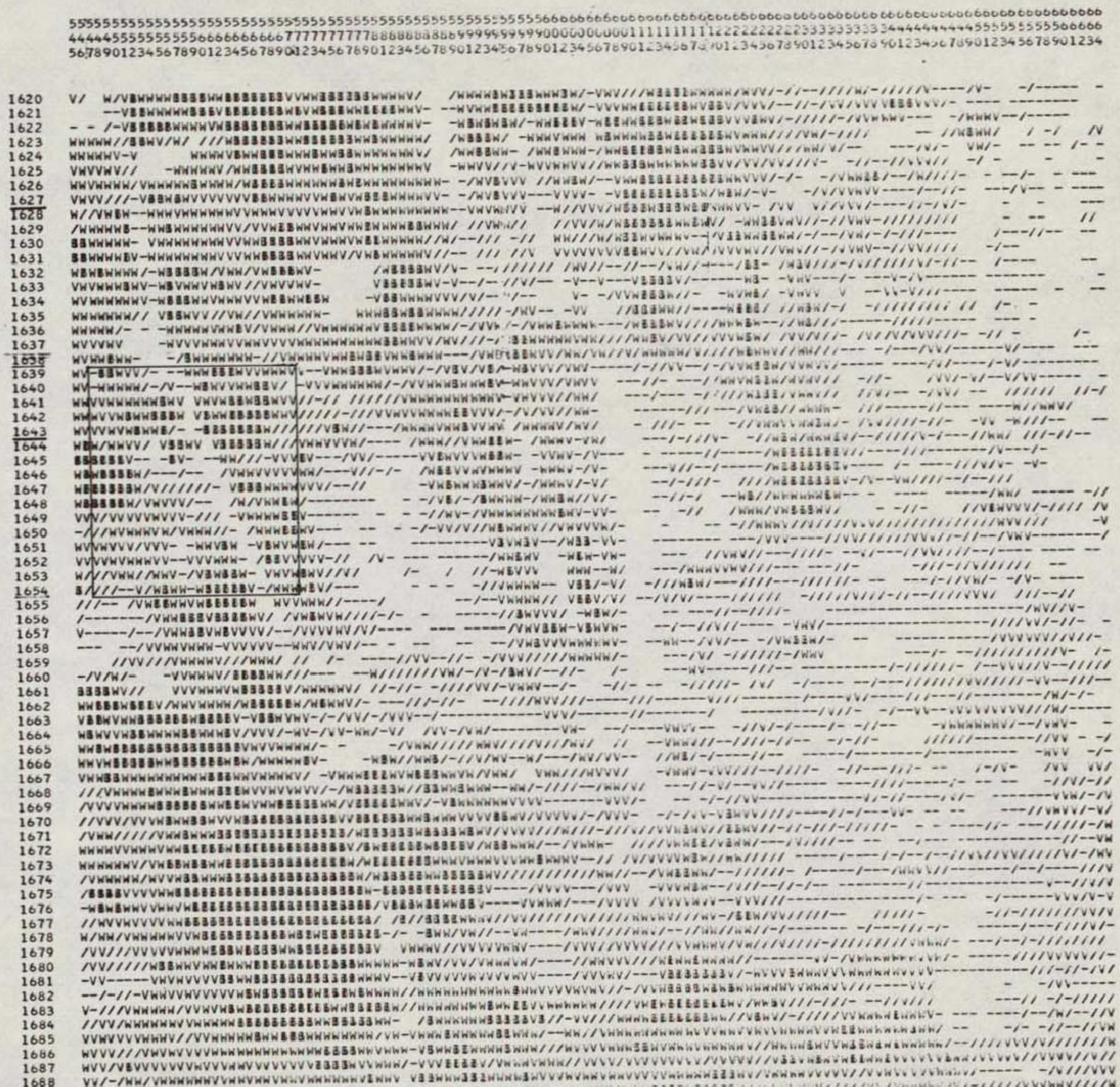


Figure 28: BAND 5 GRAY MAP OF RANG SIT AREA. The gray scale with 6 distinguishable symbols for the Rang Sit area. A rectangular subimage, whose coordinates are lines 1639 to 1654 and columns 547 to 570, is the intersection of the Pahonyotin highway and the Rang Sit canal. This subimage will be magnified to 10 x 10 times bigger by the cubic convolution interpolation technique.

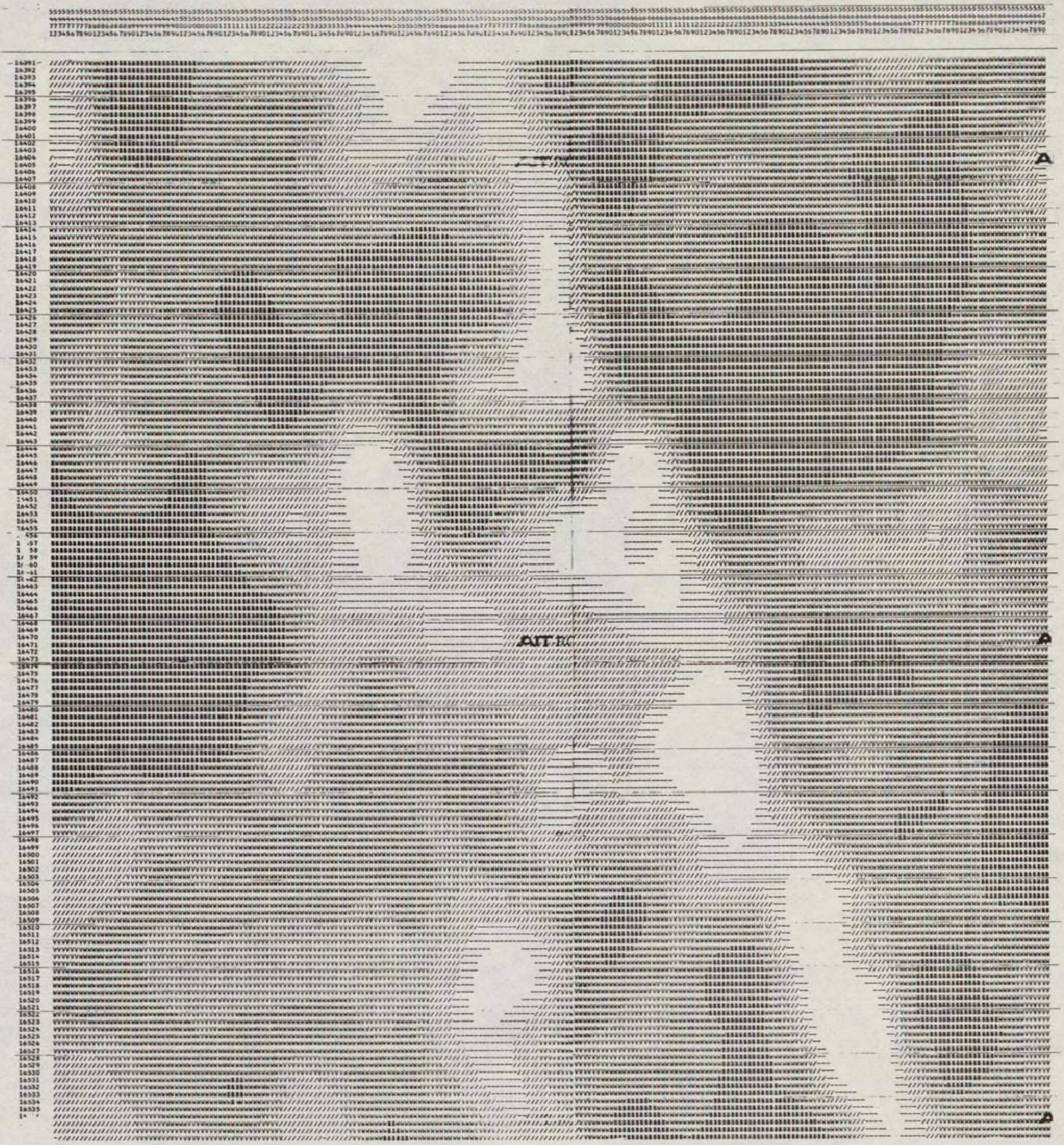


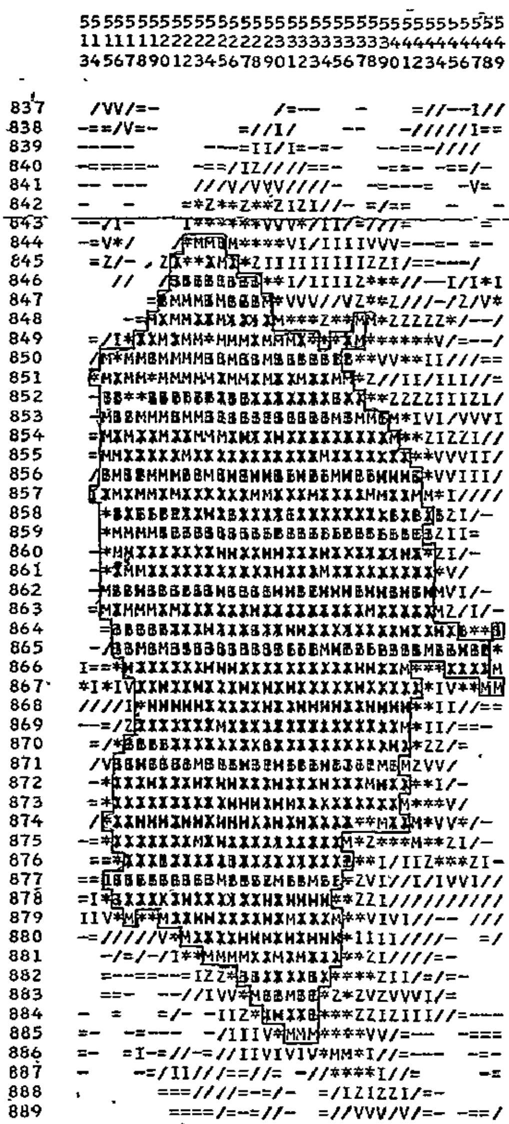
Figure 29: **BAND 5 GRAY MAP OF THE MAGNIFIED IMAGE.** Using the cubic convolution interpolation technique to enlarge a given subimage of Figure 28 to 10 x 10 times bigger. The blank area and '–' symbol represent the Pahonyotin highway.

THE CHARACTER SET USED FOR DISPLAY ISO

FROM	0.0	TO	8.50	DISPLAYED	H
FROM	8.50	TO	9.50	DISPLAYED	X
FROM	9.50	TO	10.50	DISPLAYED	B
FROM	10.50	TO	11.50	DISPLAYED	M
FROM	11.50	TO	14.50	DISPLAYED	*
FROM	14.50	TO	15.50	DISPLAYED	Z
FROM	15.50	TO	16.50	DISPLAYED	V
FROM	16.50	TO	17.50	DISPLAYED	I
FROM	17.50	TO	21.50	DISPLAYED	/
FROM	21.50	TO	25.50	DISPLAYED	=
FROM	25.50	TO	32.50	DISPLAYED	-
FROM	32.50	TO	64.50	DISPLAYED	

THE CHARACTER SET USED FOR DISPLAY ISO

FROM	0.0	TO	1.50	DISPLAYED	H
FROM	1.50	TO	2.50	DISPLAYED	X
FROM	2.50	TO	5.50	DISPLAYED	B
FROM	5.50	TO	12.50	DISPLAYED	M
FROM	12.50	TO	16.50	DISPLAYED	*
FROM	16.50	TO	18.50	DISPLAYED	Z
FROM	18.50	TO	19.50	DISPLAYED	V
FROM	19.50	TO	20.50	DISPLAYED	I
FROM	20.50	TO	21.50	DISPLAYED	/
FROM	21.50	TO	22.50	DISPLAYED	=
FROM	22.50	TO	26.50	DISPLAYED	-
FROM	26.50	TO	64.50	DISPLAYED	



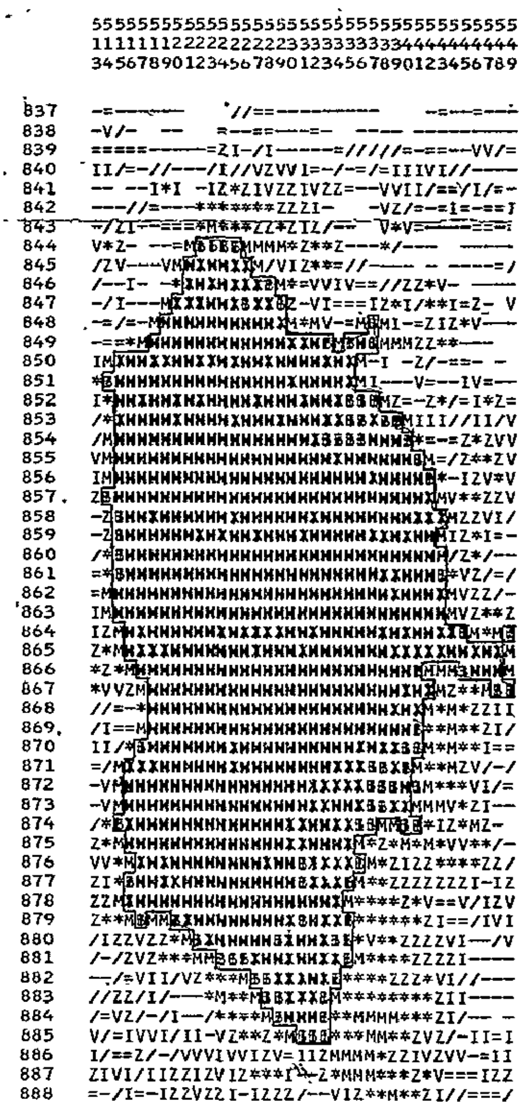


Figure 30: GRAY MAP OF BANG PRA RESERVOIR.

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HISTOGRAM OF RADIANCE

```
                                                      CLASS  RESV
          CHANNEL    1   SPECTRAL BAND  0.40  TO 0.44   MICROMETERS           EACH * REPRESENTS  35  POINTS
  525 I                  7
  490 I                  *
  455 I                  *
  420 I                  *
  385 I                  *
  350 I                  *
  315 I                  *
  280 I                  *
  245 I                  *
  210 I                  *3
  175 I                  1**       6
  140 I                  ***      8*
  105 I                  ***    * **
   70 I                  ***73 5* **2622
   35 I                 2*********9*******7*7497 635252 3 1
    0 I----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----I
     0.0                 20.00                40.00                60.00                80.00               100.00
                                                      CLASS  RESV
          CHANNEL    2   SPECTRAL BAND  0.44  TO 0.46   MICROMETERS           EACH * REPRESENTS  28  POINTS
  420 I           7
  392 I           *
  364 I           *
  336 I           *
  308 I           *
  280 I           *
  252 I           *
  224 I           *3
  196 I           **
  168 I           **2
  140 I           ***      4
  112 I          8***      *
   84 I          ****1   3*2
   56 I          *****67****51926     5
   28 I          *****************486*636178148234182 24 42   3 11 1 1
    0 I----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----I
     0.0                 20.00                40.00                60.00                80.00               100.00
                                                      CLASS  RESV
          CHANNEL    3   SPECTRAL BAND  0.46  TO 0.48   MICROMETERS           EACH * REPRESENTS  17  POINTS
  255 I       4
  238 I       4*
  221 I       **
  204 I       **
  187 I       **
  170 I       **8
  153 I       ***
  136 I       ***
  119 I       ***
  102 I       ***
   85 I       ***
   68 I      9***                            11 9      1
   51 I      ****8                       6547** * 87 2 *
   34 I      *****723                 975*******4*5**8***1*655
   17 I      *********758914542*55487*************************8894424 321    1 2     1
    0 I----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----I
     0.0                 20.00                40.00                60.00                80.00               100.00
```

HISTOGRAM OF RADIANCE

```
                                                      CLASS  RESV
          CHANNEL    4   SPECTRAL BAND  0.48  TO 0.50   MICROMETERS           EACH * REPRESENTS  31  POINTS
  465 I 9
  434 I *
  403 I *
  372 I *
  341 I *
  310 I *
  279 I *
  248 I *
  217 I *
  186 I5*
  155 I**8
  124 I***                  542
   93 I***               3268*** 7
   62 I***2             2*******7*5
   31 I*****432573649**************63
    0 I----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----I
     0.0                 20.00                40.00                60.00                80.00               100.00
```

Figure 31: CLASS HISTOGRAM OF BANG PRA RESERVOIR.

REMOTE SENSING DATA ANALYSIS

PHASE ONE

G R A Y M A P

RUN NUMBER 1 DATE NOVEMBER 6 , 1976

FLIGHT LINE AITKCC TIME 11 00

TAPE NUMBER ERTS5 ALTITUDE 9999 FEET

FILE NUMBER 1 GROUND HEADING 180 DEGREES

GRAYMAP OF CHANNEL 5 OF 7 CHANNELS

CHANNEL 5 SPECTRAL BAND 0 60 TO 0 70 MICROMETERS

THE CHARACTER SET USED FOR DISPLAY IS

FROM 0 0 TO 10 50 DISPLAYED M FROM 15.50 TO 16 50 DISPLAYED V

FROM 10.50 TO 11.50 DISPLAYED I FROM 16.50 TO 17.50 DISPLAYED I

FROM 11.50 TO 12 50 DISPLAYED A FROM 17 50 TO 18 50 DISPLAYED /

FROM 12 50 TO 13 50 DISPLAYED H FROM 18.50 TO 19.50 DISPLAYED =

FROM 13.50 TO 14.50 DISPLAYED + FROM 19.50 TO 20.50 DISPLAYED -

FROM 14 50 TO 15 50 DISPLAYED Z FROM 20 50 TO 21.50 DISPLAYED

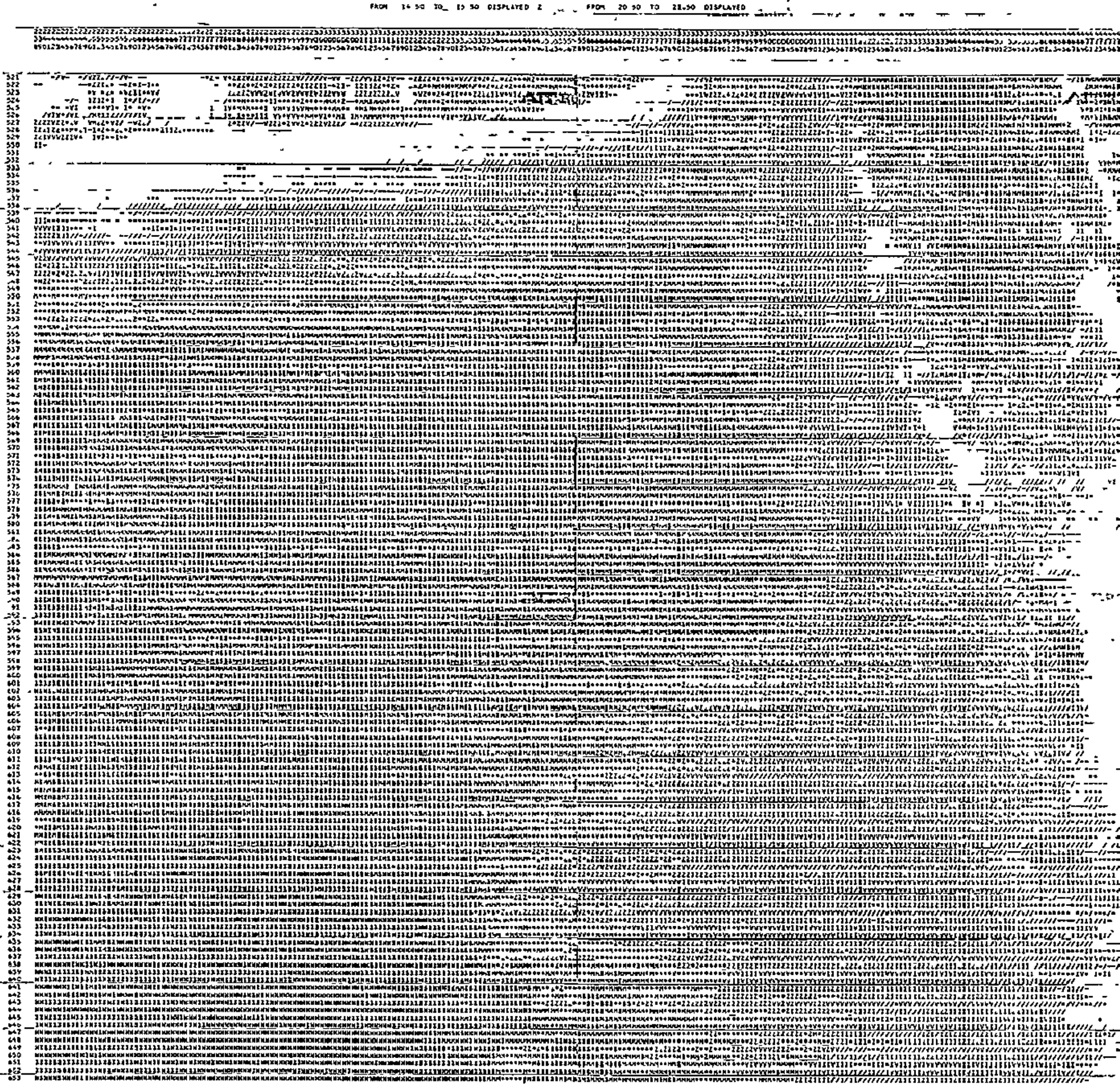


Figure 32: BAND 5 GRAY MAP FOR DELTAIC AREA OF LOWER BANG PAKONG ESTUARY.

```
                                                                 CLASS  SEDI
         CHANNEL    1   SPECTRAL BAND  0.40  TO 0.44   MICROMETERS         EACH * REPRESENTS 434  POINTS
6510 I                         9
6076 I                         *
5642 I                         *  5
5208 I                         *  *
4774 I                         *  *
4340 I                         *  *
3906 I                         * 2*
3472 I                         *8**
3038 I                        3****
2604 I                        *****6
2170 I                        *******
1736 I                        *******6
1302 I                       1********9
 868 I                      ***********
 434 I                     6***********41
   0 I----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----I
   0.0                20.00               40.00               60.00               80.00              100.00
```

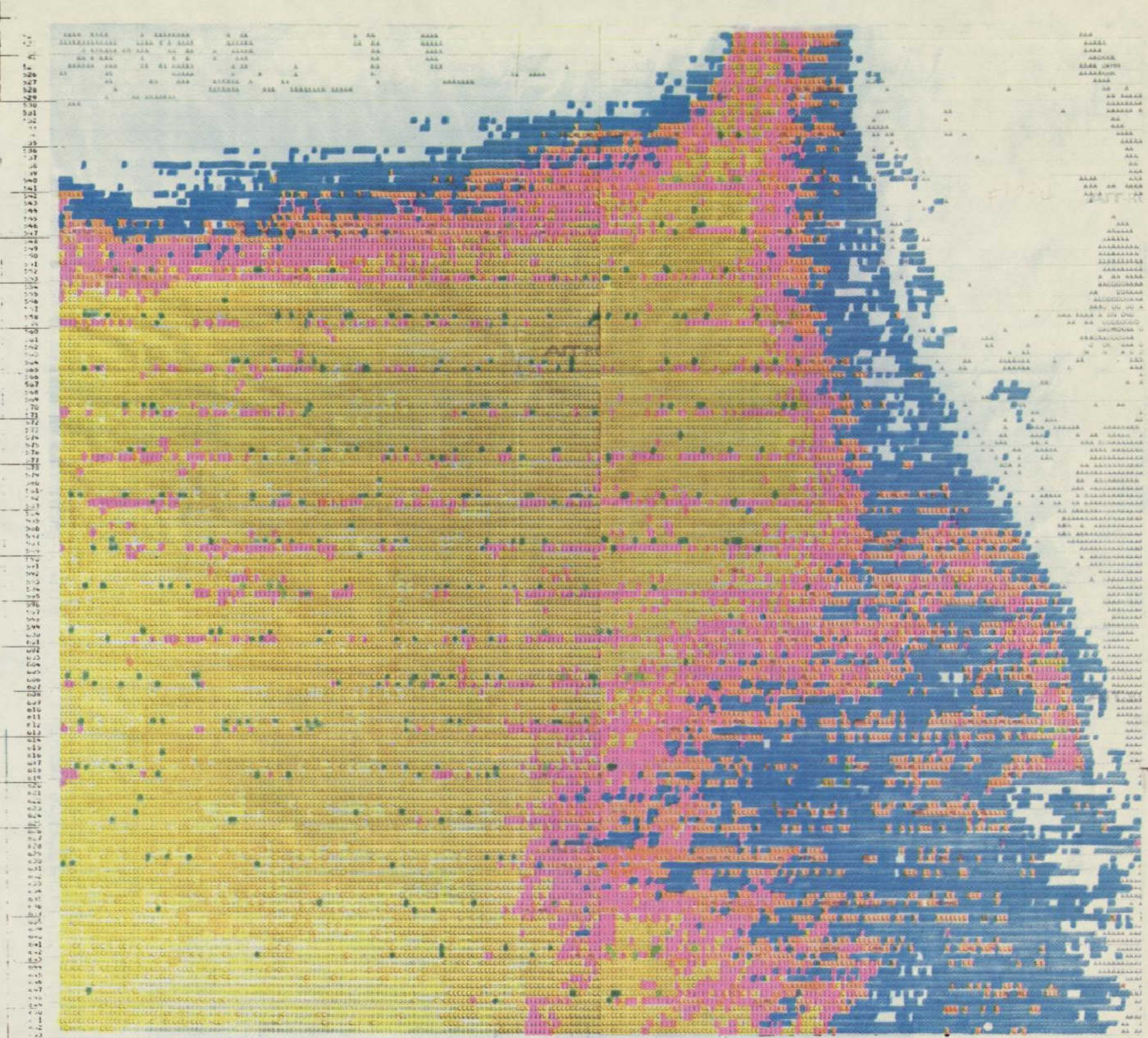
```
                                                                 CLASS  SEDI
         CHANNEL    2   SPECTRAL BAND  0.44  TO 0.46   MICROMETERS         EACH * REPRESENTS 469  POINTS
7035 I             9
6566 I             *
6097 I             *
5628 I             *6
5159 I             **
4690 I             **
4221 I             **8
3752 I             ***
3283 I             ***1
2814 I             ****47
2345 I             ******
1876 I             ******
1407 I            15******3
 938 I           1*********6 2
 469 I           ***********58311111
   0 I----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----I
   0.0                20.00               40.00               60.00               80.00              100.00
```

HISTOGRAM OF RADIANCE

```
                                                                 CLASS  SEDI
         CHANNEL    3   SPECTRAL BAND  0.46  TO 0.48   MICROMETERS         EACH * REPRESENTS 464  POINTS
6960 I      9
6496 I      *
6032 I      *65
5568 I      ***
5104 I      ***
4640 I      ***
4176 I      ***
3712 I      ***1
3248 I      ****
2784 I     9****
2320 I     *****
1856 I     *****
1392 I     *****6
 928 I     ******1
 464 I    3*******45321122122322433447657754221111
   0 I----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----I
   0.0                20.00               40.00               60.00               80.00              100.00
```

```
                                                                 CLASS  SEDI
         CHANNEL    4   SPECTRAL BAND  0.48  TO 0.50   MICROMETERS         EACH * REPRESENTS1024  POINTS
15360 I 9
14336 I *
13312 I *
12288 I *
11264 I *
10240 I7*
 9216 I**
 8192 I**
 7168 I**
 6144 I**
 5120 I**
 4096 I**
 3072 I**
 2048 I**7
 1024 I***11111111212223334321
    0 I----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----I
    0.0                20.00               40.00               60.00               80.00              100.00
```

Figure 33: CLASS HISTOGRAM FOR DELTAIC AREA OF LOWER BANG PAKONG ESTUARY.



CLASSIFICATION SUMMARY

NUMBER OF [illegible] POINTS FOR EACH CLASS WITHIN EACH FIELD AND PERCENTAGES

FIELD	CLASS	NUMBER	PER CENT
1	[illegible]	284	1.4
1	UP02	1542	9.7
1	UP03	[illegible]	38.5
1	UP04	[illegible]	1.9
1	UP05	2	0.0
1	UP06	0	0.0
1	UP07	2	0.0
1	UP08	0	0.0
1	UP09	1319	8.3
1	UP10	79	0.5
1	UP11	2	0.0
1	UP12	[illegible]	2.4
1	UP13	53	0.3
1	UP14	0	0.0
1	UP15	[illegible]	5.0
FIELD TOTAL		[illegible]	
CLASS TOTALS			

CLASSIFICATION SUMMARY

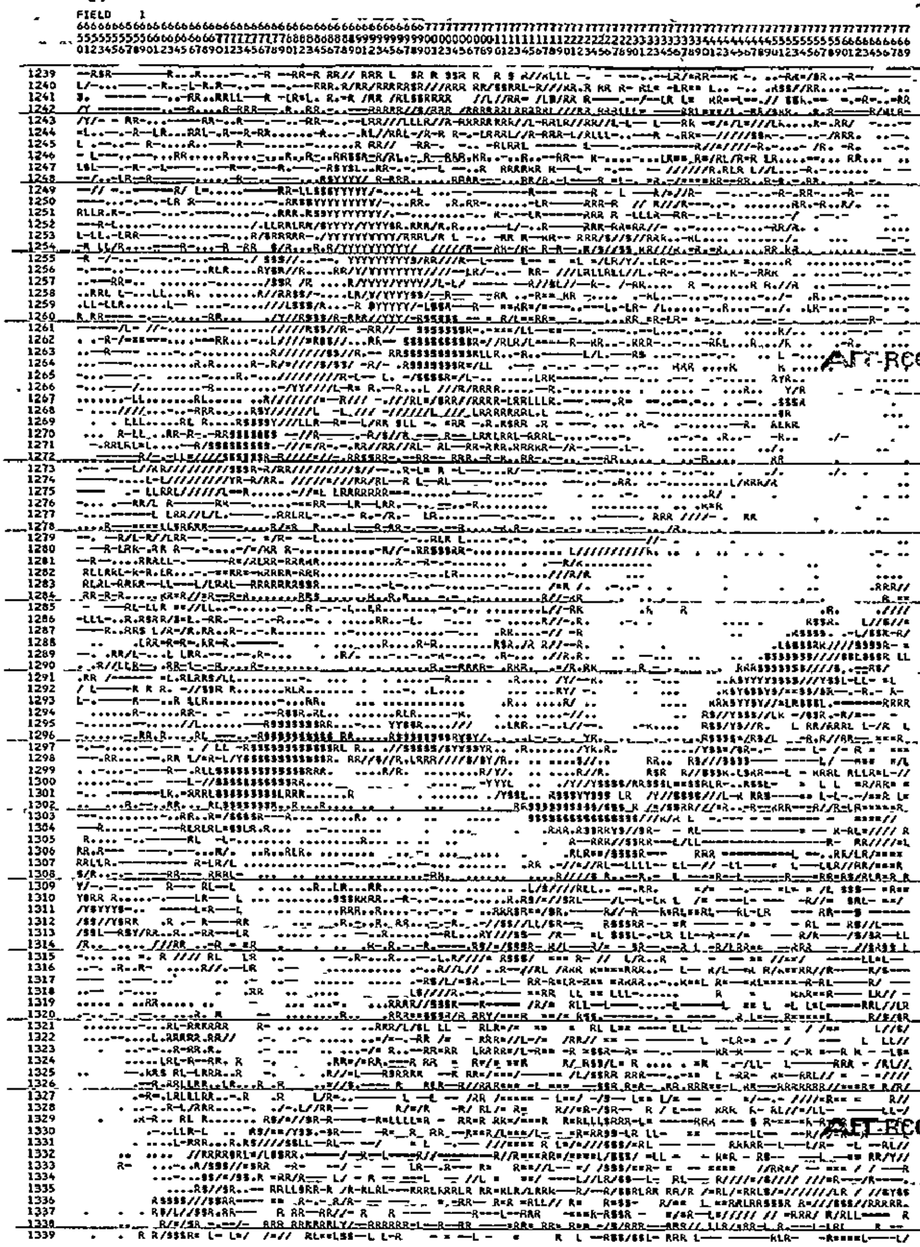
[illegible] POINTS FOR EACH CLASS WITHIN EACH FIELD AND PERCENTAGES

[illegible]	CLASS	NUMBER	PER CENT
	UP01	904	5.7
	UP02	7	0.0
	UP03	2564	16.2
	UP04	87	0.5
	UP05	0	0.0
	UP06	0	0.0
	UP07	0	0.0
	UP08	3	0.0
	UP09	1980	12.5
	UP10	115	0.7
	UP11	10	0.1
	UP12	1846	11.6
	UP13	157	1.0
	UP14	12	0.1
	UP15	4769	29.9
[illegible]LD TOTAL		15986	
[illegible]SS TOTALS			

AIT-RC

Figure 34: LEVEL RECONGITION MAP FOR DELTAIC AREA OF LOWER BANG PAKONG ESTUARY.

FIELD 1 LINES 1239 TO 1339 BY 1 COLUMNS 650 TO 769 BY 1



TEST FIELD RESULTS

FIELD	CLASS	SYMBOL	THRESHOLD	NUMBER OF POINTS	PERCENT
1	KL1		0.0	75	0.62
	KL2	*	0.0	437	3.61
	RIVE	$	0.0	20	0.17
	BARE		0.0	1532	12.64
	JUNG	$	0.0	570	4.70
	LOWT	=	0.0	2335	19.27
	UNKN	/	0.0	875	7.22
	SET1	.	0.0	2881	23.77
	SET2	Y	0.0	157	1.30
	KL3	L	0.0	602	4.97
	ROAD	R	0.0	1761	14.53
	CHCK		0.0	875	7.22

TOTAL NUMBER OF POINTS = 12120

Figure 35: GLIKE RECOGNITION MAP FOR WANG NOI DISTRICT.

Table 1/1 Application of LANDSAT Data

Agricultural, forestry, rangeland

- Crop census
- Crop yield
- Identification of vegetational disease
- Land-use inventory

Oceanography, marine-resources

- Fish production
- Ship routing
- Sea and ice conditions

Hydrology

- Water-resource inventory
- Identification of fresh water resources
- Flood monitoring
- Health monitoring of lakes
- Pollution monitoring

Geology

- Identification of tectonic features
- Geologic and physiographic mapping
- Mineral and field exploration
- Earth quake studies
- Time-rate studies: glaciers, volcanos, erosian sites

Geography

- Thematic mapping for land use
- Physical studies for land improvement

/1 Ralph Bernstien and George C. Stierhoff, "Precicien Processing of Earth Image Data", American Scientist, Vol. 64, pp. 501, Sept. - Oct. 1976.

	Electromagnetic bandwidths (μm)
12 channel MSS	.40-.44, .44-.46, .46-.48, .48-.50, .50-.52, .52-.55, .55-.58, .58-.62, .62-.66, .66-.72, .72-.80, .80-1.00,
5 channel MSS	.50-.60, .60-.70, .70-.80, .80-1.1, 10.4-12.6
4 channel MSS	.50-.60, .60-.70, .70-.80, .80-1.1

Table 2 The range of the electromagnetic bandwidths against the type of MSS.

Band 7 / Band 5	1	2	3-5	6-35
0-8	B	B	E	-
9	B	B	E	-
10	B	B	F	-
11	C	D	G	-
12-13	C	D	H	-
14	I	J	K	-
15	L	M	N	-
16-18	O	O	O	-
19-60	A	A	A	A

Table 3 Level slicing region constructed by the gray tone value in Band 5 and Band 7 with 16 distinquishable class A to O and blank symbol.