Chapter 5 : Conclusion and Proposals

5.1 Conclusion

The survey conducted in this phase has revealed the followings:

In terms of geological structure the Bicol Region can be roughly divided into three zones: the Northeastern Belt, the Central Belt and the Southwestern Belt. They lie roughly parallel to the direction in which the Bicol Peninsula extends.

The Northeastern Belt and the Southwestern Belt are characterized by distribution of Cretaceous basement rock and Tertiary intrusive rock, and the Central Belt is characterized by Pliocene to recent volcanic rock. The deposit-favorable level have been exposed and many deposits and mineral showings are reported in the Northeastern Belt and the Southwestern Belt. The types of deposits concerning which there are expectations are porphyry type copper and gold deposits, skarn type deposits and volcanogenic massive sulfide deposits. Because of distribution of recent geological bodies in the Central Belt the dissection level there has not reached the deposit-favorable level except for the northwest end, but there is possibility of epithermal gold deposit endowment in the depth.

On the basis of the results of study of existing literature, satellite image analysis and the ground truth survey and taking into account the situation regarding establishment of mining claims, the following areas are considered to be promising:

- Northeastern Belt: The Mt. Bagacay area in Camarines Norte, the Larap-Exiban area and the eastern part of the Caramoan Peninsula

- Central Belt: The Kilbay area in Camarines Sur, the northwest part of the the Tiwi-Mt. Malinao area in the vicinity of the border between Camarines Sur and Albay, the western part of the Bacon-Manito area near the border between Albay and Sorsogon and the Gate Mountains area in the southern part of Sorsogon

- Southwestern Belt: The Tuba area

5.2 Proposals for the Phase II Study

It is desirable that the following kinds of surveys be implemented in the second year in the promising areas identified in the preceding section, "Conclusion."

Regarding the promising areas in the Central Belt, it is possible that there are epithermal gold deposits in them in the depths. It is therefore necessary to carry out surveys that make it possible to surmise the places and depths of possible existence of deposits. For instance, it might be possible to determine places of up-welling of deep hydrothermal fluid by analysis of the chlorine content of the altered rock, which is an phenomenon of the shallow part of epithermal systems. At the same time, there should be detailed study of areas of distribution of fracture systems with the same direction as that of fracture systems constituting reservoir of nearby active geothermal systems. It is also a good idea to considering drilling for the purpose determining trend of alteration zones at different depths, their temperature gradient and whether or not there is possibility of mineralization.

It is also necessary to survey in detail the areas in the vicinity of existing mineral showings in promising areas lying in the Northeastern Belt and the Southwestern Belt.

Attention should be given to the following points in surveying the different areas:

The Mt. Bagacay area:

This area includes several iron skarn deposits and mineral showings, and on the south side there are gold and base metal mineral showings of the metalliferous vein type. They suggest the possibility of existence of porphyry type deposits. It is needed that systematic study of existing skarn mineral deposits and mineral showings, the assemblage of metallic ore minerals and fluid inclusion homogenization temperature for the purpose of depicting the temperature structure within the area. Intrusive rock stocks will also be looked for detailed surveying in their vicinity. In the United Nations (1987) survey of the Tabas area biotite, wollastonite and andalusite were noted as altered minerals, and two of the samples contained pyrophyllite. They represent acid alteration in which a porphyry system is developed nearby. It is therefore desirable that the Tabas area also be included in the survey.

The Larap-Exiban area:

Since this area is comparatively extensive and has distribution of many deposits and mineral showings in it, it will be difficult to narrow down the areas to be surveyed. Since Philex Corp., Altas Corp. and other companies have done prospecting in it, that data should be obtained as far as possible so that it can be analyzed as a means of narrowing down the area of the survey. Furthermore, since there is distribution of many intrusive rock stocks in this area and since it is considered that most of the deposits and mineral showings in it were formed in connection with such intrusive rock, it is desirable to get a precise idea of its distribution and to undertake detailed surveying in the vicinity of it.

Eastern part of the Caramoan Peninsula:

This area was not included in the ground truth survey this year because of its situation regarding establishment of mining areas and because of poor access, but the latest information received from BMG Region V indicates that those problems have been solved. In this area there is distribution of mineral showings of the volcanogenic massive sulfide type deposit in the greenschist and mica schist, and they are characterized by mode of occurrence roughly concordant with the schistosity of such schist. It is therefore thought to be necessary to determine its structure, horizons and facies at existing mineral showings so as to be able to estimate extension thereof.

The Tuba area:

In the Tuba area it is necessary to survey veins and alteration zones at known mineral showings to determine whether it is a matter of the vein-type deposits as in the Paracale area or epithermal deposits. If they are determined to be of the vein-type, the vicinity of the intrusive rock thought to belong to the Tertiary period and the fracture systems in the vicinity of existing mineral showings and with the same direction will be surveyed. If they are determined to be of the epithermal type, in view of the connection with the Nalesbitan deposit in terms of position fracture systems that both have in common will be surveyed.

The Kilbay area:

This area was not included in the ground truth survey this year because of insufficient information and the schedule. However, it is considered to be a promising area in terms of possibility of pervasive hydrothermal systems since the volcanic rock distributed in it is hornblende andesite and it is surmised that the magma involved in deposit formation contained more water than other volcanic rock zones. Therefore it is desirable that it be surveyed in the second year of the present study.

The northwestern part of the Tiwi-Mt. Malinao area:

The existence of alteration zones was confirmed on the basis of floats in this year's survey.

From the state of distribution it is surmised that the alternation zones lie at the upper reaches of the Santa Cruz River and the Cayohoson Creek. The NE-SW system of faults (Kagumihan fault, Tiwi fault and Naglagbong fault) forming the main reservoir of the Tiwi geothermal development area and the NW-SE Tutsan-Bolo fault are the main ones. In this area there is also extensive NW-SE and NE-SW lineaments. The area of distribution of such fracture systems is considered to be important because of the fact that the intersection of those two lineaments just about coincides with the upper reaches of the Santa Cruz River and the Cayohoson Creek.

The western part of the Bacon-Manito area:

The low resistivity area from the Cawayan River to Calpi is surmised to have a comparatively high gold potential. The upper reaches of the Cawayan River are situated in the Bac-Man fault zone, which has an E-W direction. Furthermore, since the slope of the upper plane of the Calpi steam-heated alteration zone is roughly parallel to the river's present hydraulic gradient, it is surmised that the upflow region is situated on the further upstream side of Calpi creek. That upstream side is superimposed upon the Bac-Man fault zone, and it is therefore necessary that the survey be centered on that fault zone.

Gate Mountains area:

Since the results of the ground truth survey this year point to the possibility that the hydrothermal activity in the area extending from the vicinity of Tugas north of Mt. Sujac to Culasi on the southeast side was controlled by fractures in the NW-SE direction, surveying along those fractures is considered necessary. Furthermore, many floats of silicified rock and altered rock were noted along the coast in the southwest part of the Gate Mountains area. Although it is not yet clear which fracture controlled the hydrothermal system that caused such alteration, it is considered necessary to survey the upstream side of the creek considered to be the source of those floats.

In the above three areas what are thought to be alteration zones on the basis of the results of the airborne magnetic survey will be surveyed, as will the fracture lines passing through them. Moreover, it is also considered to be important to determine the age of the volcanic rock and the alteration and mineralization, which it was not possible to do adequately in this year's survey.

PART II DETAILED DESCRIPTION

Chapter 1: Analysis of Existing Information

1.1 General Description of Agencies for the Study and Existing Information

(1) Agencies visited for collection of data

Mines and Geosciences Bureau (MGB) in Manila
Mines and Geosciences Bureau (MGB) in Legazpi
Department of Energy
University of the Philippines
Philippine Institute of Volcanology and Seismology
Philippine National Oil Company (PNOC)
Philippine Geothermal Inc. (PGI)
Phitex Mining Corporation

(2) General description of collected data

About 200 documents were collected. The area covered by each document was plotted into 1/250,000 scale topography (See Fig. II-1-1) and was listed with keywords. (Appendix Table 1-1)

From these documents, information for mineral showings and alteration zone were summarized. Based on such information, possible ore deposits were estimated to select the promising area.

In the geothermal survey areas performed by PNOC, drilling sample (core and sludge) as well as the report were obtained to analyze characteristics of the rock and altered ore.

The air-borne magnetic survey map covering the entire Philippine performed by the World Bank was obtained from the Department of Energy. This is also used for selection of promising areas.

1.2 Type and Breakdown of Collected Data

(1) Duplicated and collected documents

Collected documents are shown in Appendix Table 1-1.

(2) Published topography maps

The entire regions for survey are covered by 42 1:50,000 scale topography maps and 5 1:250,000 scale topography maps. The positions of the collected topography maps are shown in Fig. II-1-2.

For 1:50,000 scale topography map, the following original maps of 35 regions were obtained:

3462-I, II, 3561-I, II, III, 3562-I, II, III, 3563-II, III, 3627-I, II, 3660-I, III, IV, 3661-II, III, 3662-II, III, 3726-II, 3758-I, II, IV, 3759-I, II, III, IV, 3760-III, IV, 3761-I, II, 3826-III, IV, 3859-III, IV

Topography maps of 3627-I, II, 3726-II, 3627-I, II and 3826-III, IV have been edited and newly published after 1990. Other topography maps have been edited before 1990.

Copies were obtained for the following 8 regions because the original maps were not obtained: 3560-I, 3561-IV, 3562-IV, 3660-II, 3661-1, IV and 3761-III, IV

For the map of 1:250,000, the original maps for the following 4 regions were obtained: PCGS 2513 (PANDON), PCGS 2515 (LUCENA CITY), PCGS 2516 (LEGAZPI CITY) and PCGS 2519 (BULAN).

Copy was obtained for PCGS 2512 (DAET) because the original map was not obtained.

In addition, the following maps were obtained:

- Administrative Map	Region V Bicol	1:250,000
- Administrative Map	Province of Camarines Norte	1:150,000
- Administrative Map	Province of Camarines Sur	1:150,000
- Administrative Map	Province of Albay	1:150,000

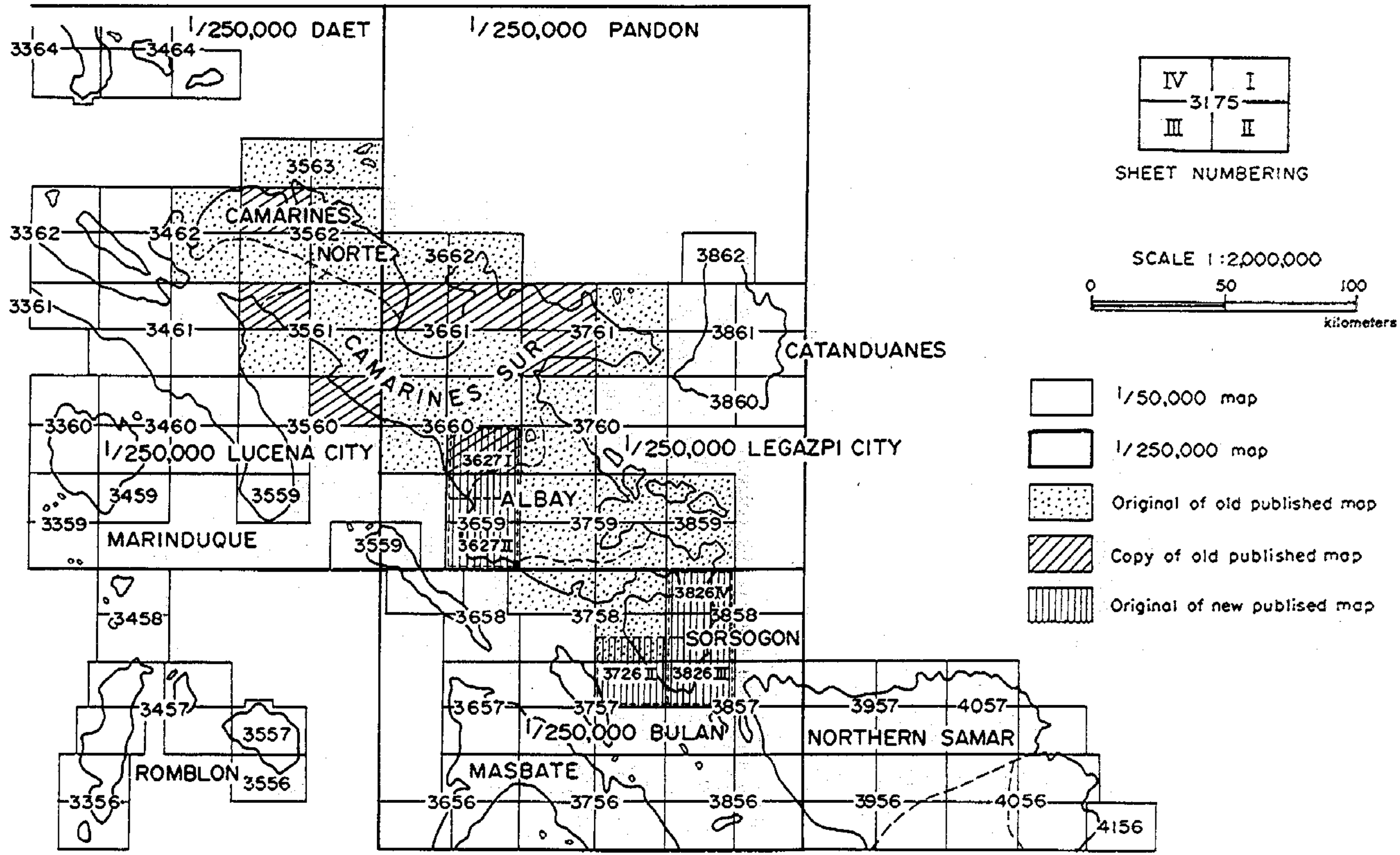


Fig.II-1-2 Index map of the obtained topographic maps

- Administrative Map	Province of Sorsogon	1:150,000
- Map of Sorsogon Province Showing the Road System		1:100,000
- Legazpi City	Urban Area and Vicinity Map	1:10,000

(3) Geological map

In this survey region, existing BMG geological map (1:50,000) and wide area geological map (1:250,000) for Bicol generated by BMG Region V branch were collected. Fig. II-1-3 shows the coverage area of collected topography maps.

Original maps for the following 24 regions were obtained as existing BMG geological map (1:50,000) for the coverage areas:

3462-I, II, 3560-1, 3561-I, II, III, 3562-I, II, III, IV, 3563-II, III, 3659-I, II, 3661-I, II, III, IV, 3662-II, III, 3761-1, II, III, IV

Copies of white maps were obtained for 2 regions of 3858-III and 3758-II.

Mineral Potential of the Bicol Area (1:250,000) was obtained as an edited drawing apart from geological maps.

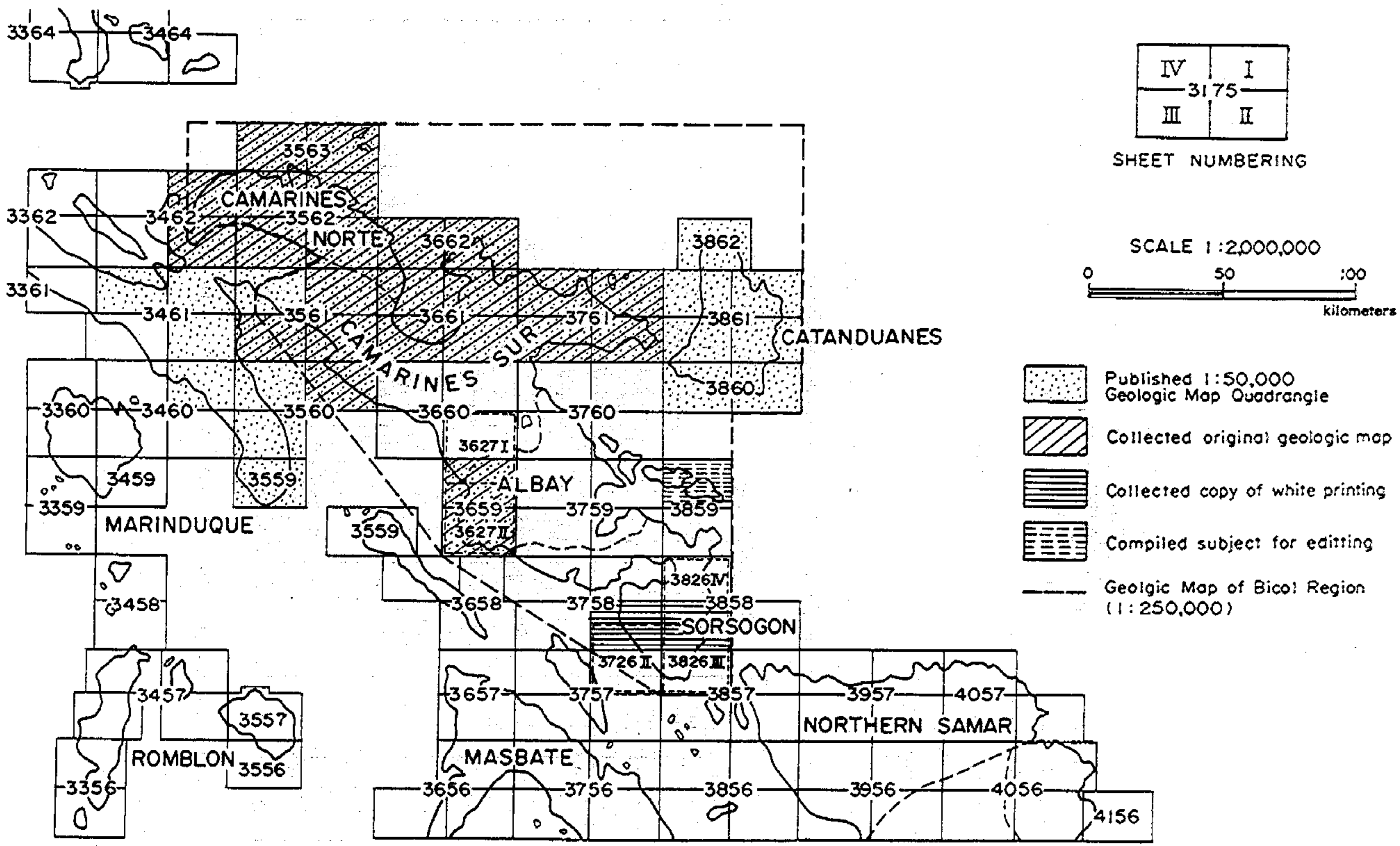


Fig.II-1-3 Index map of the obtained geological maps obtained

2.1 Processing and Generation of Image

2.1.1 Purpose and Method

The purpose of this survey is to process the LANDSAT-TM image data and the JERS-I/SAR image data for the survey areas, to analyze the image in geological point of view, and to contribute to selection of promising areas based on the analysis of the result together with existing information. It is important that lineament related to metallic ore deposit or rare metallic ore deposit is selected, and that lithofacies, lithology and alteration zone in the survey area are classified accurately. The goal is to select the promising area through analysis.

2.1.2 Data to be used

The satellite image data used in this survey is the LANDSAT-TM image data (4 scenes) and the JERS-I/SAR image data (13 scenes). Each image specification is shown in Table II-2-1.

Table II-2-1 Specification of satellite imagery

LANDSAT-TM			Scene center		Sunlight		Quantity of cloud
path	row	date	latitude	longitude	elevation	azimuth	Q1 Q2 Q3 Q4
114	050	05/03/1992	13:29:46	123:39:20	58.66	82.32	20 10 10 10
114	051	04/071994	13:14:47	123:38:54	55.24	98.00	10 10 10 10
115	050	02/14/1990	13:59:36	122:13:30	44.15	125.12	40 10 10 0
115	051	04/19/1996	13:44:49	122:13:20	54.36	90.34	10 0 20 10
JERS-1/SAR			Scene center		Sunlight		Quantity of cloud
path	row	date	latitude	longitude	elevation	azimuth	Q1 Q2 Q3 Q4
083	278	12/09/1996	13:28	124:09	------	------	----------
083	279	12/09/1996	12:52	124:02	------	------	----------
083	280	12/09/1996	12:16	123:55	------	------	----------
084	277	12/10/1996	14:04	123:43	------	------	----------
084	278	12/10/1996	13:28	123:36	------	------	----------
084	279	12/10/1996	12:52	123:29	------	------	----------
085	277	12/11/1996	14:04	123:10	------	------	----------
085	278	12/11/1996	13:28	123:03	------	------	----------
085	279	12/11/1996	12:52	122:56	------	------	----------
086	277	07/03/1995	14:04	122:38	------	------	----------
086	278	07/03/1995	13:28	122:31	------	------	----------
087	276	12/13/1996	14:39	122.11	------	------	----------
087	277	12/13/1996	14:04	122:04	------	------	----------

Air topography map (1:500,000, TPC K-11B: Philippine Islands) published by the US Defense

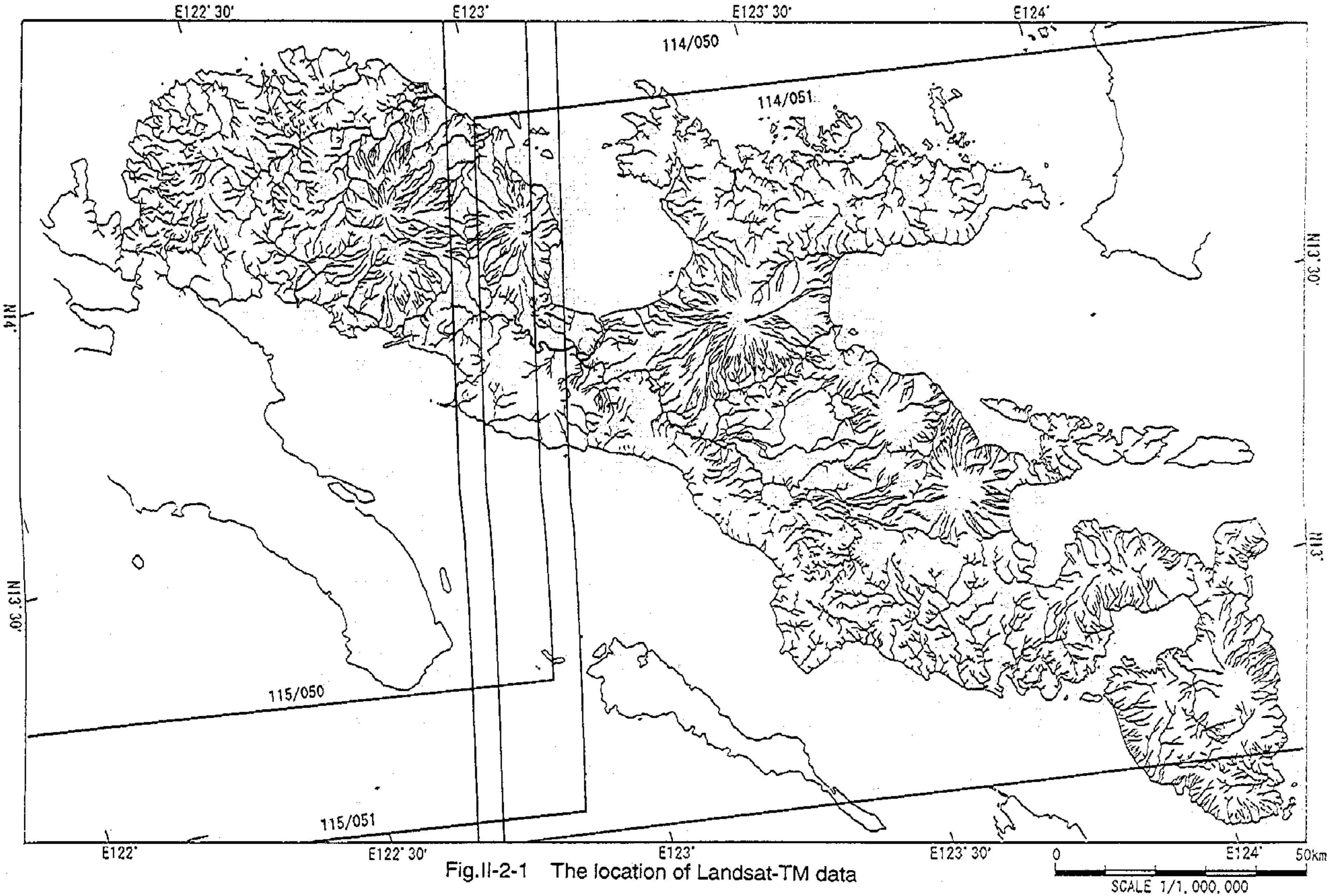


Fig.II-2-1 The location of Landsat-TM data

Mapping Agency was used for projection of satellite image UTM map.

2.1.3 Data Processing and Generation of Image

(1) LANDSAT TM

1) Selection and acquisition of image data

Since the survey area belongs to the tropical zone, the area is always covered by clouds. The LANDSAT-TM image data with 0% cloud has not been observed yet. The observation data with the least cloud in the survey area was selected for each 4 scenes.

The LANDSAT TM image data for the survey area was received at the Thai station (NRCT). Therefore, the LANDSAT-TM image data of the selected scenes was obtained from Thai station (NRCT). To obtain the LANDSAT-TM image data, instructions to move the scene center to the south or north were given so that each selected scene may cover the survey area and that large overlapping of the scene in the north/south direction may be taken. (Fig. II-2-1) Thus, selecting less cloud areas from the north/south scenes can reduce influence of cloud on the entire survey area. The movement of the scene center is as follows:

Path Row	Date	North latitude	East longitude	Center movement
114 050	May 3, 1992	13:29:46	123:39:20	40% to south
114 051	Apr. 4, 1994	13:14:47	123:38:54	10% to north
115 050	Feb. 2, 1990	13:59:36	122:13:30	30% to south
115 051	Apr. 19, 1996	13:44:49	122:13:20	50% to south

2) Image processing

Many parts of the survey area are covered by vegetation. Exposure of rocks reflecting geology and alteration zone was rarely found. Therefore, photo-geological analysis with attention morphological expression would be the most effective. Based on this method, the following image processing and color composite image were generated.

a) Various corrections

Noise reduction process

Various types of noise that disturbs analysis must be eliminated for generation of images. In general, deficiency line, stripe noise and random noise can be found.

Deficiency lines have already been corrected through the standard process at the Thai station. In this case, correction was not made.

Stripe noise in the sample direction or the line direction that may affect analysis was not found on the image data used.

Considering that the image for analysis is 1:250,000 scale, noise elimination with smoothing or median value filter was not performed to prevent poor spatial resolution.

Offset of registration between bands was not observed in the image data used.

UTM map projection

The LANDSAT-TM image data is basically projected in UTM. The axis is calculated from the satellite orbit information. It may not be accurate enough for the purpose of analysis. In this survey, the air topography map (1:500,000, TPC K-11B: Philippine Islands) published by the US Defense Mapping Agency was used. The UTM map was projected by setting GCP.

Edge enhancement and gray level adjustment

The edge was enhanced using a spatial filter (3 x 3 Laplacian). In photo-geological analysis, attention is paid to morphological expression. It is necessary to enhance geological changes and lineament.

Systematic difference in gray level (DN: digital number) was found between the image data of scenes used due to differences of observation dates and sun elevations. It is desirable that the brilliance of each scene is identical in analysis. The brilliance should be suitable for analysis. In this survey, adjustments have been made for the gray level between scenes and the gray level to be suitable for analysis by multiplying DN of each scene by a factor.

b) Generation of mosaic image

Using 4 scene images in the survey, the digital mosaic image data covering the entire survey area was generated.

Image data of each scene has already been projected with the UTM map. In principle, arrangement of each image data on the coordinates can generate the mosaic image data. However, offset of a few pixels (approx. 100 m) may occur at the joint. In the survey, GCP was set between joint scenes to establish precise positioning.

In addition, many small areas were set at the overlapping areas between joint scenes. Image data of scene with less clouds than the others was selected for each small area. Thus, influence from cloud has been reduced.

c) Generation of color composite image

In this survey, false color images for each scene (4 scenes) and 4 scene mosaic images were generated from band combination (BGR=234) suitable for geological analysis. (See Fig. II-2-2.) Many parts of survey areas were covered with vegetation and exposed rocks reflecting geological and alteration zones were rarely found. Therefore, photo-geological analysis that indicates morphological expression would be the most effective. In this band combination (BGR=234), most of vegetation areas has become red-orange. The image is not affected by difference of vegetation. This facilitates analysis of topographical information.

Assuming that existing information such as geological map, topographical map and ore deposit map and the analysis result are integrated, latitude and longitude were indicated around the image. Color scale and contraction scale were also placed to allow correct printing on the photographic paper.

d) Generation of rationing image

The LANDSAT-TM image having 7 bands in the range from visible and near infrared ray to thermal infrared ray provides useful information for analysis of lithofacies and alteration zone in the rock exposure area such as a desert. As previously explained, many parts of the survey area is covered with vegetation. Normal color composite images rarely shows the rock exposure reflecting the geology and the alteration zone.

Assuming that areas other than vegetation, cloud (cloud and shadow) and waters are the rock exposure areas, rationing images were generated. To remove vegetation, cloud and waters, the threshold value was established against the DN value and the band ratio. The threshold value was determined through trial and error with a value considered suitable for each scene.

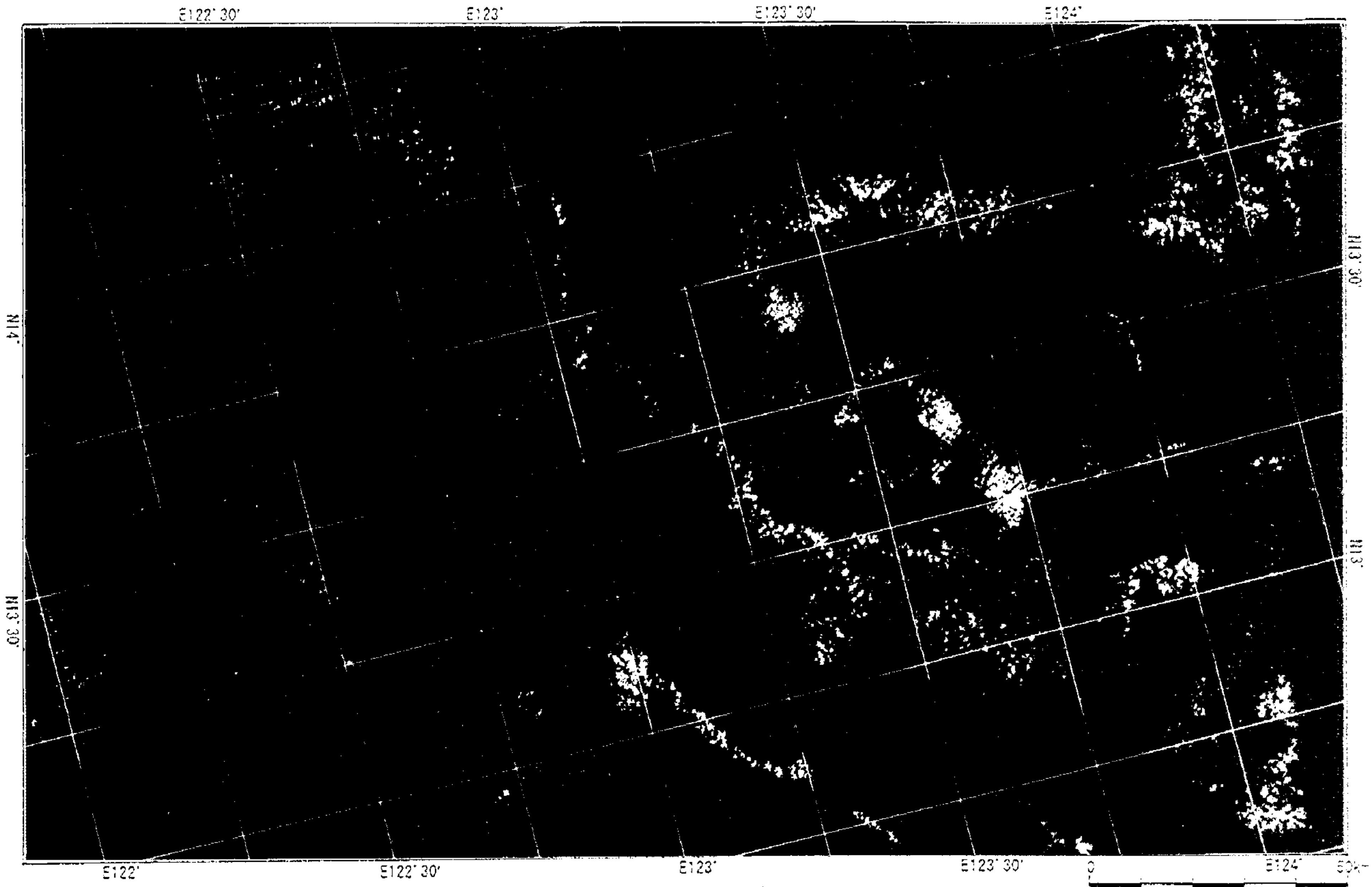


Fig.II-2-2 Mosaic of Landsat-TM false color composite of the Bicol Area (BGR:234)

For the land that may have no vegetation, rationing image was generated with combination of BGR - Band 3/Band 1, Band 5/Band 4, and Band 5/Band 7 used for general analysis of alteration zones(See Fig. II-2-3). The sea was displayed in dark gray and other areas were displayed in white. This process is effective for analysis of vegetation areas becaouse only the areas considered to be rock exposure were displayed in color and the land is separated from the sea.

Assuming that existing information such as geological map, topographical map, ore deposit map is compared with the analysis results, latitude and longitude were indicated around the image. Color scale and contraction scale were also placed to allow correct printing on the photographic paper.

e) Others

Supervised classification, using the spectrum information of the alteration zone distributed around the existing ore deposit for training, has been implemented to take out the alteration zones in relation to ore deposits and mineral showings. However, the vegetation percentage is very high and the gray level calibration between LANDSAT-TM scenes was not sufficient. Preferable results were not then obtained.

(2) JERS-1/SAR

1) Selection and acquisition of image data

Since JERS-1/SAR is a synthetic aperture radar (SAR), it is not much influenced by clouds or the sun. The requirements for selection of observation data were that the scene in the same path must show the same observation date and that the scene in the adjacent path must show the consecutive observation date. However, there is no data that satisfies these requirements.

In this survey, the scenes of paths 083 - 085 and 087 have met the above requirements. 2 scenes in path 086 could not satisfy the requirements of adjacent path and consecutive observation dates. Therefore, the observation date nearest to other path was used. (See Fig. II-2-4.)

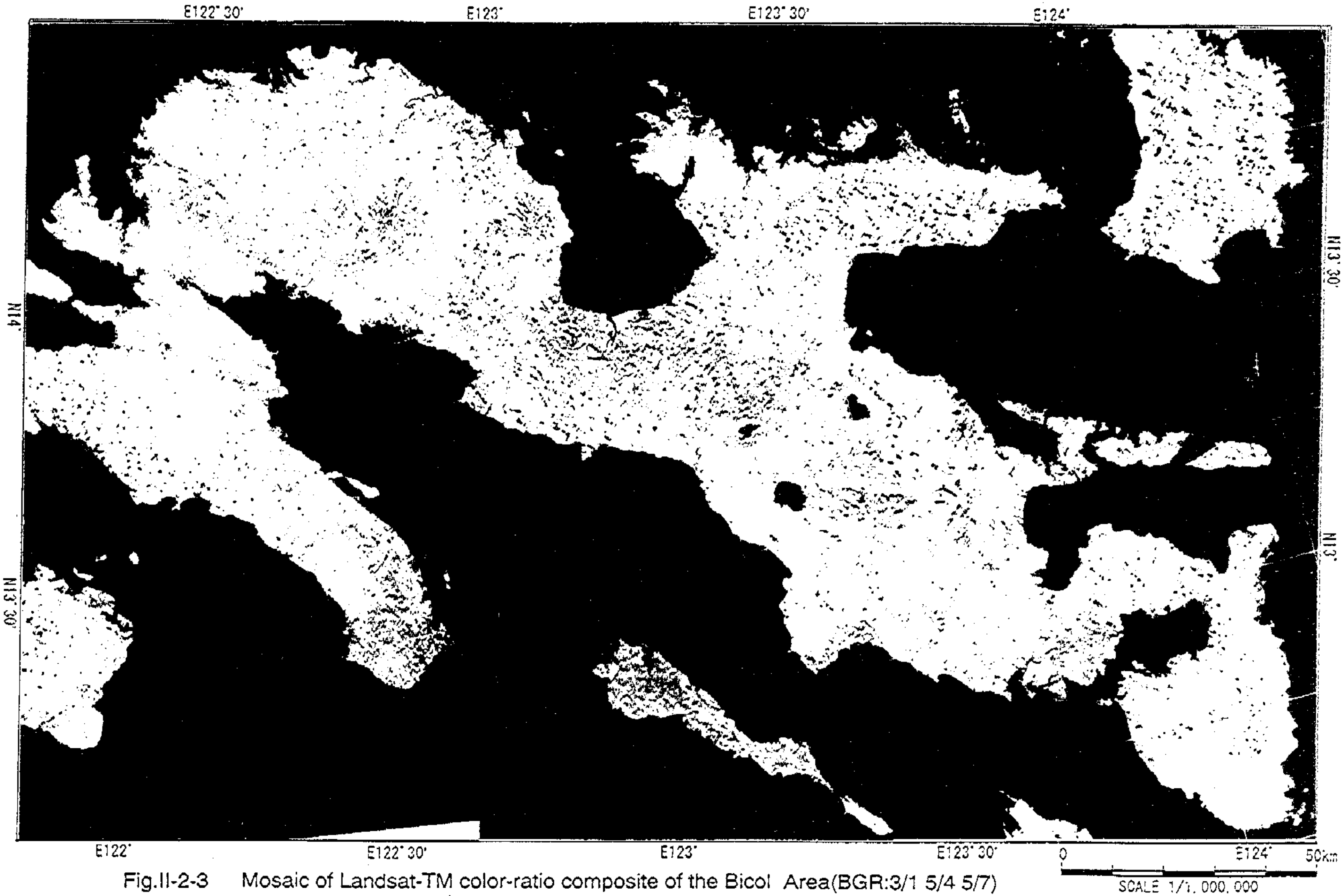


Fig.II-2-3 Mosaic of Landsat-TM color-ratio composite of the Bicol Area(BGR:3/1 5/4 5/7)

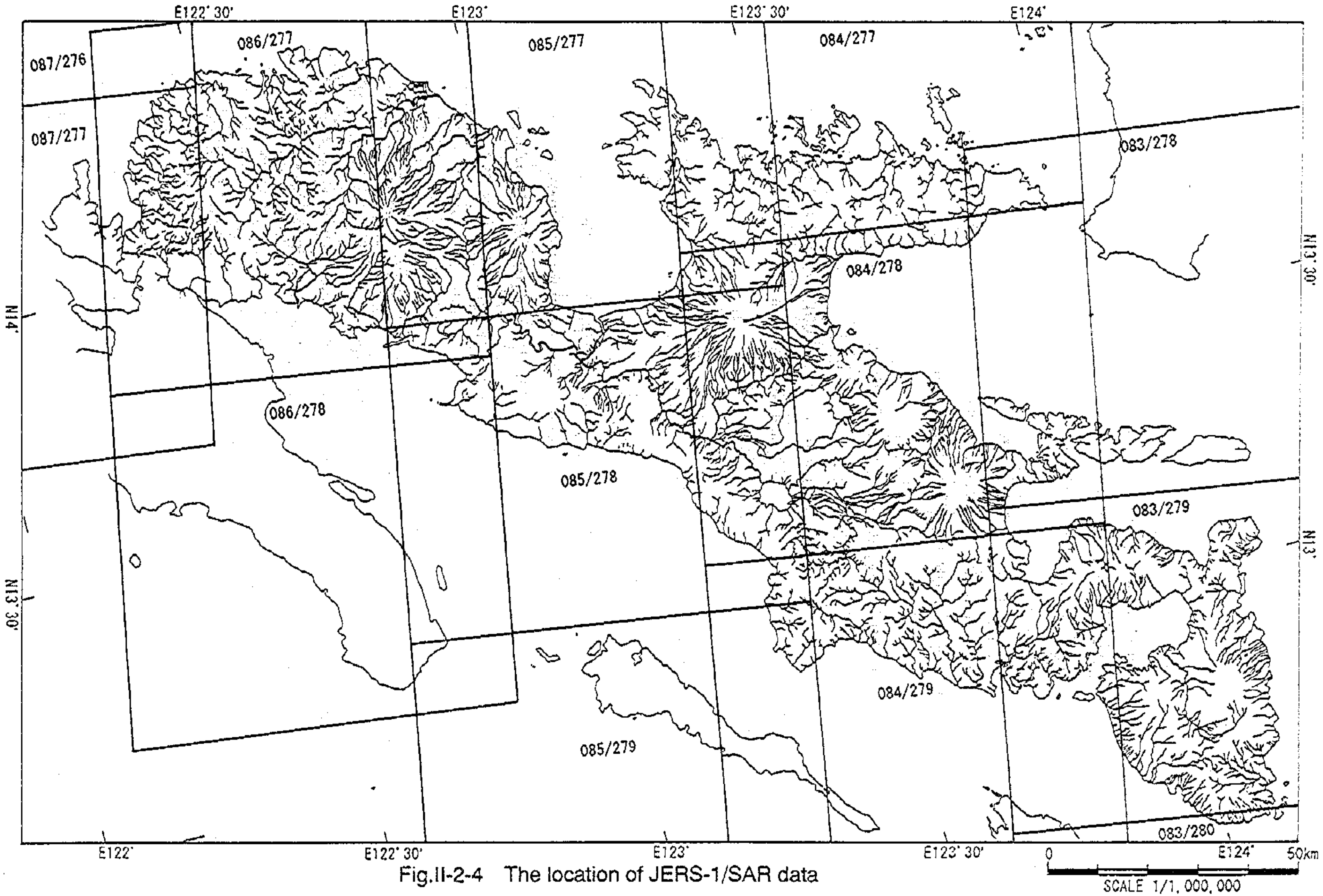


Fig.II-2-4 The location of JERS-1/SAR data

2) Image processing

a) Various correction process

Noise reduction process

Various types of noise that disturb analysis must be eliminated for generation of images. Generally, the synthetic aperture radar (SAR) tends to show a larger random noise compared to the optical sensor. In this survey, spatial filter (5 x 5 median filter) was used to reduce random noise.

The gray level (DN) in JERS-1/SAR, tends to vary in the upward/downward (east/west) direction. In this survey, correction was made using the sea area of Line1-6400/Sample2601-4000 at P083/R277. The gray level (DN*) in this sea area is approximated to:

DN* (line) = 564.63 - 0.0837 x line + 1.2055E - 5 x line 2

In this approximate expression, the minimum value (about 420) is present at the center of the line. Using the above approximate expression and the minimum value, the gray level after correction (DN**) is:

DN **(line) = DN (line) + 420 - DN* (line)

UTM map projection

The JERS-1/SAR image data is basically projected in UTM. The coordinates are calculated from the satellite orbit information. They are not sufficiently accurate for the purpose of analysis. In this survey, the air topography map (1:500,000, TPC K-11B: Philippine Islands) published by the US Defense Mapping Agency was used. The UTM map was projected by setting GCP.

Gray level adjustment and edge enhancement

The gray level of the JERS-1/SAR image data shows a distribution similar to Poisson distribution. In linear gray level adjustment, images that represent both bright and dark areas cannot be generated. In photo-geological analysis, it is preferable that the gray level is close to the 6 aussian distribution. In this survey, for adjustment of the gray level (DN***) suitable for analysis, logarithmic conversion of the gray level was made using the conversion formula:

DN*** = ln (DN**) x 117 – 695

In addition, the edge was enhanced using the spatial filter (3 x 3 Laplacian). In photo-geological analysis, morphological expression is usually emphasized. It is also necessary to enhance topographical changes or lineament.

b) Generation of mosaic image

Using 13 scene images in the survey, the digital mosaic image data covering the entire survey area was generated. (See Fig. II-2-5.)

Image data of each scene has already been projected with the UTM map. In principle, arrangement of each image data on the coordinates can generate the mosaic image data. However, offset of a few pixels (dozens of meters) may occur at the joint. In the survey, GCP was set between joint scenes to establish precise positioning.

c) Generation of image

In this survey, black and white images for each scene (13 scenes) and 13 scene mosaic images were generated for geological analysis. Assuming that existing information such as geological map, topographical map and ore deposit map and the analysis result are integrated, latitude and longitude were indicated around the image. Gray scale and contraction scale were also placed to allow correct printing on the photographic paper.

2.2 Analysis of Image

2.2.1 Criteria of Geological Analysis

(1) Factors for analysis and selection and their criteria

a) Analysis of geological interpretation unit

Factors and criteria for geological interpretation unit and their criteria are as follows:

1) Photo-geological characteristics (LANDSAT-TM false color image and JERS-1/SAR black and white image)
Tone: Color on the image
Texture: Smoothness, small grain, medium grain, rough grain

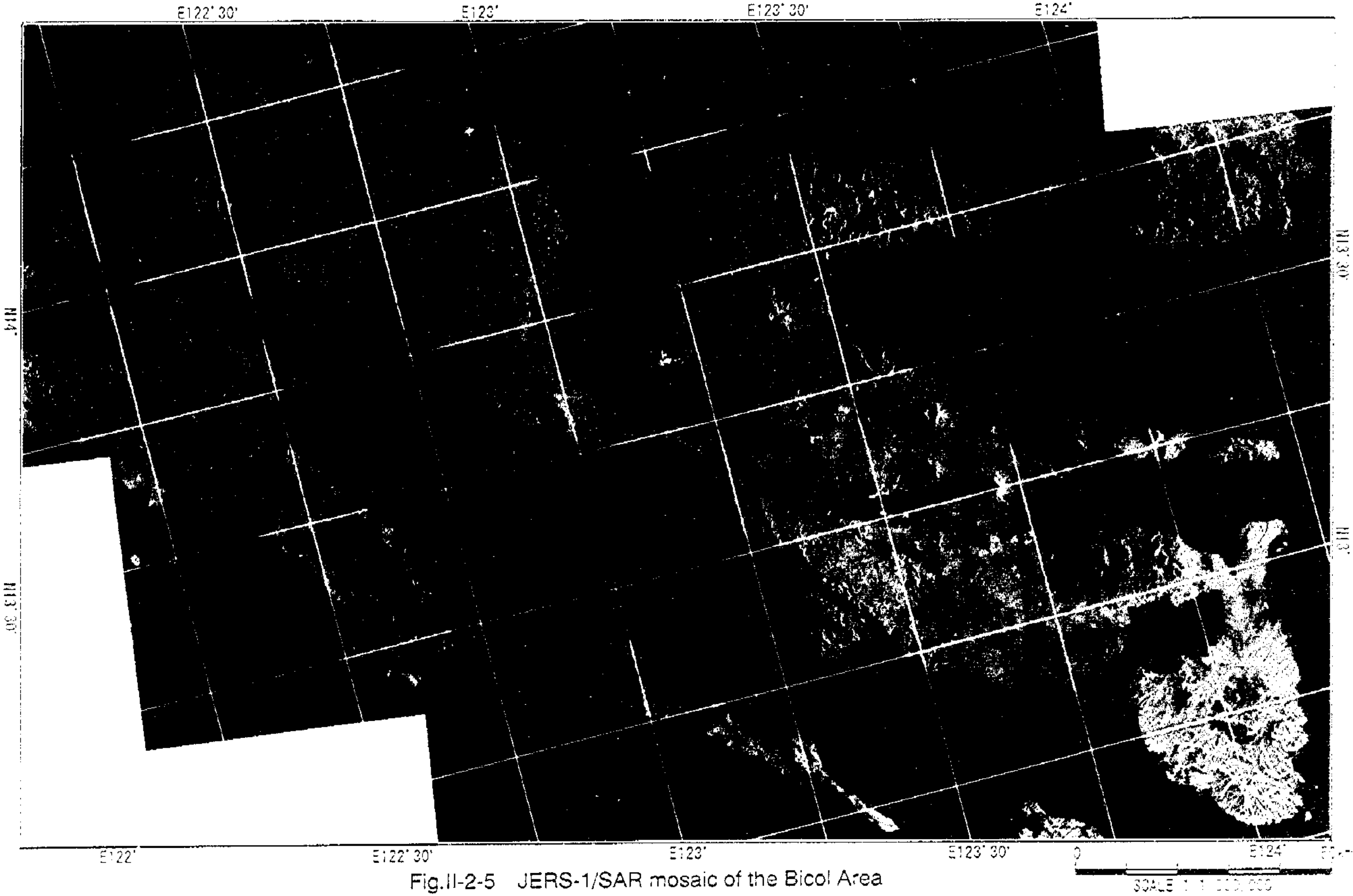


Fig.II-2-5　JERS-1/SAR mosaic of the Bicol Area

2) Morphological expression (mainly JERS-1/SAR black/white image)
Drainage pattern: Branch, parallel, grid, radiation, annual ring, meandering
Drainage density: Extremely high, high, medium, low, extremely low
Rock resistance: Extremely high, high, medium, low, extremely low
Cross section: Waviness, shape of ridge and valley
Development of bedding: Bedded to massive

3) Vegetation (LANDSAT-TM false color image)
Vegetation density: Dense - not dense

b) Analysis of geological structure (LANDSAT-TM false color image and JERS-1/SAR black and white image)

Factors for analysis of geological structure and their criteria are as follows:

Stratum tracing: Selection of topography showing bedding (cuesta, flat iron, etc.) is used for analysis.

Folding structure: Distribution of identified geological interpretation unit and topography showing bedding (cuesta, flat iron, etc.) are used for analysis.

Fault structure: Discontinuity of identified geological interpretation unit or bedding, and various faults that appear at the rivers and ridge lines are used for analysis.

Ring structure: Caldera or crater topography is used as a cave-in fracture. Volcanic topography is used as a cone structure.

Lineament: Linear morphological expression reflecting the underground rupture is used as lineament. Lineament that is considered to be a fault or a main structure line is separated.

c) Extraction of alteration zone (LANDSAT-TM rationing image)

The rationing image consists of blue = Band 3/Band 1, green = Band 5/Band 4, and red = Band 5/Band 7 for the land which is considered to be no-vegetation area. Therefore, foreseeable alteration minerals are as follows:

Red: Argillic zone

Red purple: Argillic zone with iron oxides

Yellow - brown: Argillic zone with iron oxides

Green - blue: Iron oxides

From the rationing images, areas that showing these tones in concentration are selected as alteration zones. Medium gray tone areas are classified into one of the above considering peripheral tones. Whether the non-vegetation land is rock exposure area or cultivated area cannot be determined at present. All of applicable areas are selected.

(2) Characteristics of analysis factors in the survey area

For geological interpretation unit in analysis of satellite images in the survey area, rock resistance, drainage density, drainage pattern and texture in the photo-geological factors were especially effective.

Rock resistance showed high values in the distribution area of rocks in the old geological time and new volcanic rocks. On the other hand, drainage density has no relation to geological time and represents ruptures or development of bedding. Thus, in this survey, geological items are grouped by combination of rock resistance and drainage density. Here, rock resistance is grouped into H, M and L and drainage density is grouped into h, m and l. Geological item with high rock resistance and high drainage density is referred to as Hh. Geological item with medium rock resistance and low drainage density is referred to as Ml. Further, detailed geological interpretation unit from Mh1 to Mh6 is made according to other factors.

At and around the new volcanoes, the drainage pattern is radiant and the topographical section is volcanic. The geological items having these characteristics are represented with prefix V as in VHm2.

The results of lineament from LANDSAT-TM and JERS-1/SAR show some difference in visibility (clear or not clear) and many of lineaments are identical. All directional lineaments were uniformly selected from LANDSAT-TM. But some areas are covered with clouds and ground resolution is below half of JERS-1/SAR. The selected number of lineaments is less than those of JERS-1/SAR. On the other hand, images from JERS-1/SAR are not influenced by clouds and they have high ground resolution, and the selected number of lineaments is more than those of

LANDSAT-TM. In this case, appearance of lineament is concentrated in NE-SW and NW-SE directions. This means that the topography that intersects with the radiating direction from the synthetic aperture radar is enhanced in the case of JERS-1/SAR.

Many of promising alteration zones are concentrated at low deposits, falling stratum around volcanoes and part of sedimentary rocks in interpretation unit for geological analysis. These areas are close to densely populated or roads. Judging from this, it is possible that many of promising alteration zones can be cultivation areas with less vegetation. However, the tones on the result of rationing shows some variation. If alteration zones are cultivation areas, the image tone would be reflecting the soil type corresponding to the geological conditions in the peripheral areas.

2.2.2 Classification of Geological Units

(1) Result of geological interpretation from photo images

Geological units were classified by from the result of photographic interpretation (Table II-2-2, Figure II-2-6). Geological units were classified roughly from the resistivity, drainage texture density and drainage texture pattern. Geological units were further subdivided according to the differences in other elements. As a result, 38 geological interpretation units were distinguished. The following shows outlined interpretation units based on the resistivity. The distribution of these geological interpretation units are also shown in Table II-2-3.

*Geological interpretation unit: V***

The geological interpretation units mainly showing radial drainage texture in volcanic topography are classified into 8 types, most of which are of VH (radial drainage texture pattern with high resistivity), corresponding to younger volcanoes. However, the surroundings of volcanoes are of VM to VL (radial drainage texture pattern with medium to low resistivity).

Geological interpretation unit: Q

The areas in alluvial soil nearly without undulations are put together and the geological interpretation unit Q. These units are widely distributed at the center of Bicol Peninsula and also dotted along the coast.

*Geological interpretation unit: H***

The geological interpretation units showing high resistivity (H) were classified into 6 types, Hh1 to 4, Hm1 and Hl1, depending on the differences in the drainage texture density and other

Table II-2-2 Detailed features of satellite imagery and geologic units

units		photographic aspects of SAR/TM imagery		geographical features					vegetation	distribution
imagery	geologic	color tone	aspects of fabric	tributary pattern	density	resistivity	profile	bedding		
VHh1	V5	medium / medium	fine / fine	radial	high	high		massive	dense	Mt.Culasi, Mt.Bintacar
VHh2	NV3	medium /medium or light	fine / fine	radial	high	high		massive	dense	Manito/S
VHm1	V1	medium light / medium light	smooth / smooth	radial	medium	high		massive	dense	V.Bulsan, V.Bacon/W
VHm2	V2	medium / medium light	fine / fine	radial	medium	high		massive	dense	Mt.Masatoga, Mt.Isarog
VHm3	V3	medium / medium dark	fine / fine	radial	medium	high		massive	dense	Mt.Labo
VHl	V4	medium / medium dark	fine / fine	radial	low	high		massive	dense	V.Mayon, Mt.Malinao, Mt.Iriga
VMh	V	medium / medium	fine / fine	parallel	high	medium		massive	dense	Mt.Labo, Mt.Culusi
VLl	V	medium light / medium light	fine / smooth	dendritic	low	low		massive	dense	slope or depression of margin of volcano
Q	Q	dark or medium/dark or medium	spotted / spotted	dendritic or meander	low	low		massive	thin or medium	depression
Hh1	BC1	medium / medium light	fine or medium / fine	dendritic	high	high		massive	dense	Caramoan
Hh2	BC2	medium / medium	fine or smooth / fine or smooth	dendritic	high	high		massive	dense	Camarines Norte
Hh3	Pg	medium / medium light	fine / fine	latticed	high	high		massive	dense	Panganiran
Hh4	NV4	medium / medium	fine / fine	dendritic	high	high		massive	dense	Irosin/S, Mt.Marina/N
Hm1	BC1	medium light /medium or medium dark	smooth / fine	dendritic	medium	high		massive	dense	Caramoan
Hl1	BC2	medium light /medium or medium dark	smooth / fine	dendritic	low	high		massive	dense	Camarines Norte
Mh1	BC1	medium light / medium light	medium / smooth	dendritic	high	medium		massive	dense	Caramoan
Mh2	Gr1	medium / medium	medium / medium	rectangular	high	medium		massive	dense	Paracare
Mh3	Gr2	medium / medium	medium / medium	rectangular	high	medium		massive	dense	Panganiran
Mh4	M4	medium dark / medium dark	coarse / coarse	rectangular	high	medium		massive	dense	Caramoan
Mh5	N1	medium / medium	medium / medium	latticed or rectangular	high	medium		massive	dense	Albay to Camarines Sur/SW
Mh6	N2	medium dark / medium	rough / rough	rectangular	high	medium		massive	dense	Albay
Mm1	BC1	medium dark / medium	smooth / smooth	dendritic	medium	medium		massive	dense	Rapu Rapu
Mm2	M4	medium / medium	coarse / medium	dendritic	medium	medium		massive	dense or medium	Caramoan, Rapu Rapu
Mm3	M1	medium light / medium dark	fine / fine	dendritic	medium	medium		massive	dense or medium	Albay to Camarines Sur/SW
Mm4	M2	medium / medium	medium / medium	dendritic	medium	medium		massive	dense	Paracare
Mm5	NV1	medium dark / medium	fine / fine	dendritic	medium	medium		massive	dense	Paracare to Sorsogon
Ml1	BC1	medium dark / medium dark	smooth / smooth	dendritic	low	medium		massive	dense	Rapu Rapu
Ml2	M1	medium / medium light	smooth / smooth	parallel	low	medium		massive	dense	Albay to Camarines Sur/SW
Ml3	M1	medium / medium	smooth / smooth	parallel	low	medium		little	dense	Albay to Camarines Sur/SW
Lh1	M3	medium / medium	medium / medium	dendritic	high	low		little	dense	Camarines Norte
Lh2	N1	medium / medium	fine / fine	rectangular	high	low		massive	dense	Albay to Camarines Sur/SW
Lm1	M1	medium / medium	medium / medium	dendritic	medium	low		massive	dense	Camarines Norte
Lm2	M4	light / medium	fine / fine	dendritic	medium	low		massive	dense	Bacon/E
Lm3	N3	medium light / medium	fine / fine	dendritic or parallel	medium	low		massive	dense	Bacon/SE
Lm4	NV2	medium light / medium	fine / fine	dendritic	medium	low		massive	dense	Sorsogon
Ll1	BC1	medium / medium light	fine or smooth / smooth	dendritic	low	low		massive	dense	Caramoan/W
Ll2	M4	medium light / medium	fine / smooth	dendritic	low	low		massive	dense	Rapu Rapu
Ll3	N3	medium or dark/medium or dark	smooth / spotted	meander	low	low		massive	dense or medium	Legaspi/S

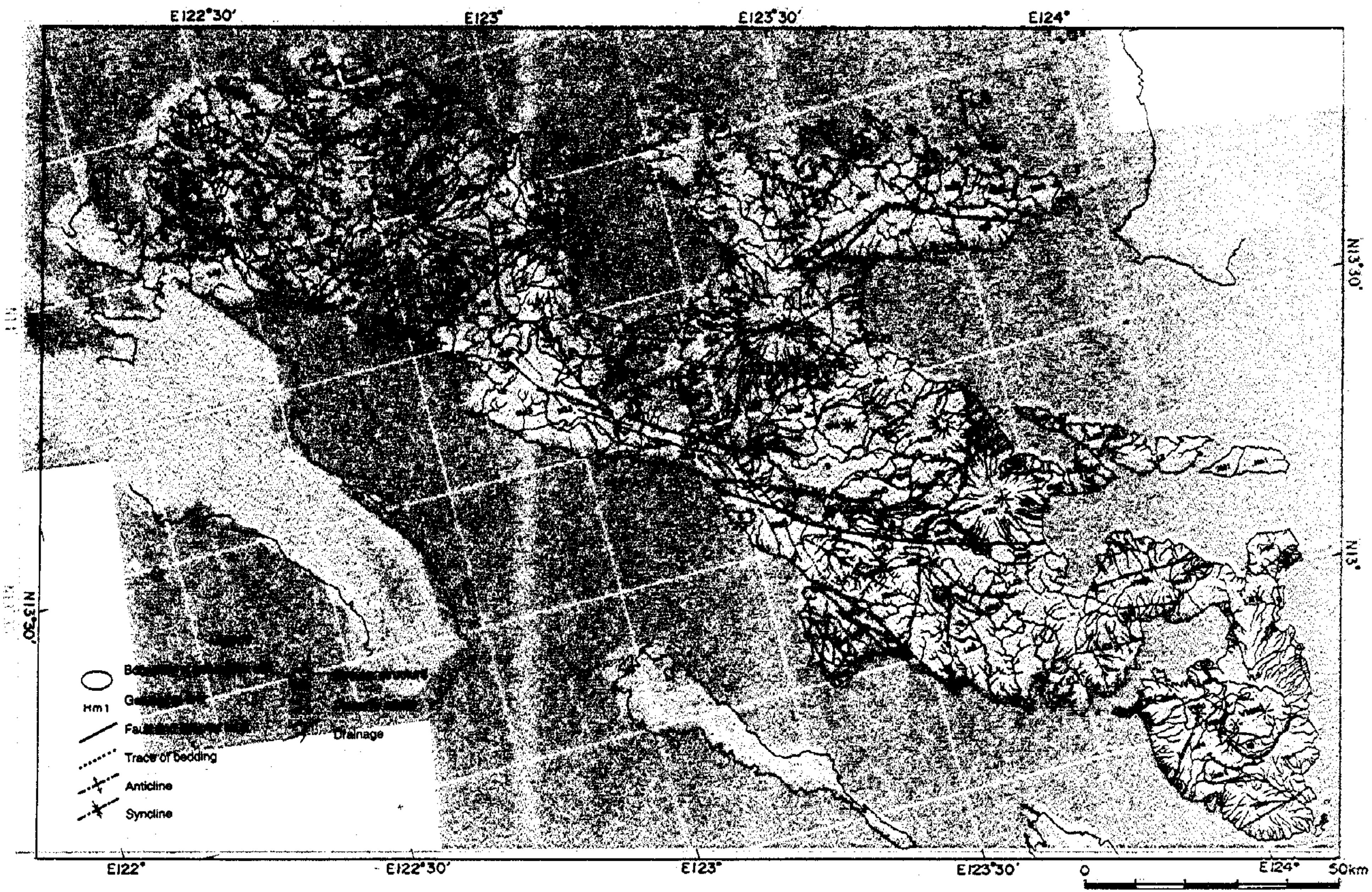
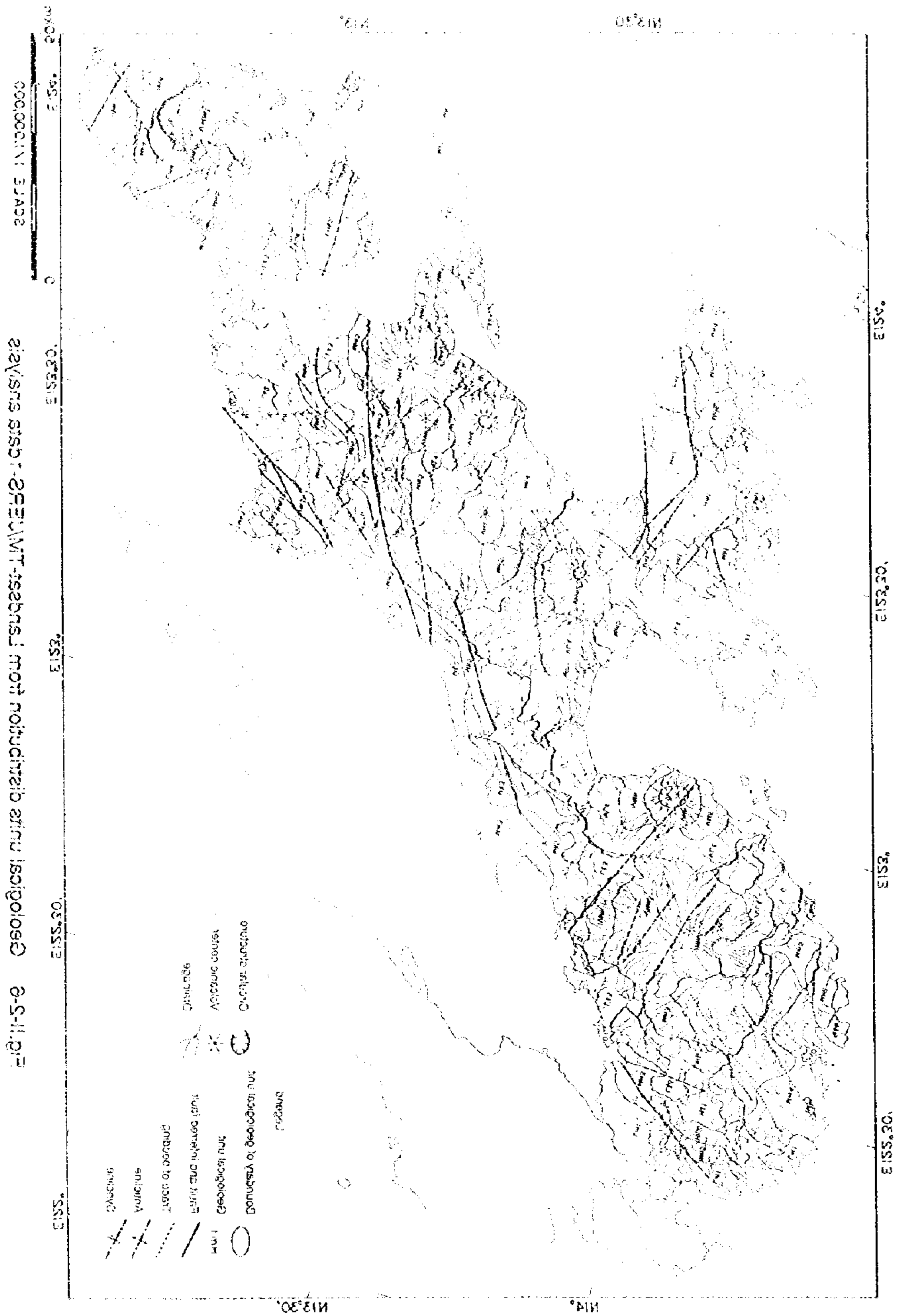


Fig.II-2-6 Geological units distribution from Landsat-TM/JERS-1data analysis



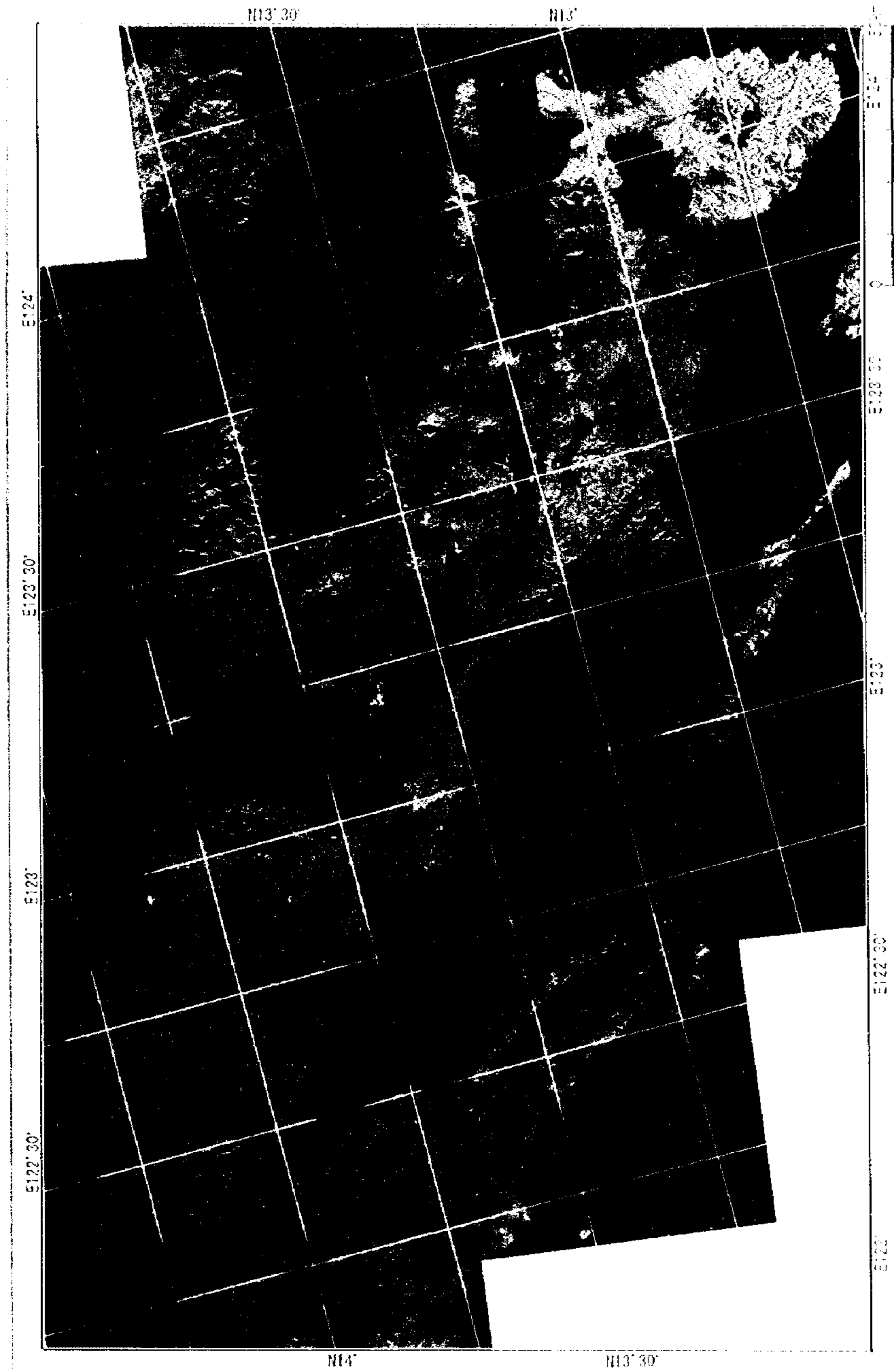

N13°30'
N13°
E124°
E123°30'
E123°
E122°30'
E122°
N14°
N13°30'

Table II-2-3 Correlation between satellite imagery unit and geologic unit

imagery unit		geologic unit		geology and lithology suggested by comprehensive interpretation
Q		Q		Quaternary and/or allubium
Ll3	Lm3	N3		Pliocene to Pleistocene sedimentary rocks with coralline limestone
Mh6		N2		
Lh2	Mh5	N1		
Lm1	Ll2	M1	M4	Miocene sedimentary rocks
Ml2	Lm2			
Ml3	Mh4			
Mm3	Mm2			
Mm4		M2		
Lh1		M3		
Hh3		Pg		Paleogene sedimentary rocks
Hh1	Mh1	BC1		pre-Tertiary and ultrabasic rocks
Hm1	Ml1			
Ll1	Mm1			
Hh2	Hl1	BC2		

VHm1		V1	Quaternary volcanic rocks
VHm2		V2	
VHm3		V3	
VHl		V4	
VHh1		V5	
VLl	VMh	V	volcaniclastic rocks
Mm5		NV1	Tertiary volcanic rocks
Lm4		NV2	
VHh2		NV3	
Hh4		NV4	

Mh2	Gr1	Intrusive body of Granitic rocks
Mh3	Gr2	

elements.

All these units are the areas with rich geographical undulations, mainly distributed in Caramoan Peninsula and south of Sorsogon Peninsula.

*Geological interpretation unit: M***

The geological interpretation units showing medium resistivity (M) were classified into 14 types, Mh1 to 6, Mm1 to 5 and Ml1-13, depending on the differences in the drainage texture density and other elements.

These units are widely distributed in the whole survey area, corresponding to the areas with small and loose geographical undulations.

*Geological interpretation unit: L***

The geological interpretation units showing low resistivity (L) were classified into 9 types, Lh1 to 2, Lm1 to 4 and Ll1-13, depending on the differences in the drainage texture density and other elements.

All these units are widely distributed in the whole survey area, corresponding to the areas with a small number of geographical undulations.

(2) Result of geological analysis

The geological interpretation units classified by photographic geological interpretation were analyzed in comparison to the existing informations (Table II-2-3, Figure II-2-7). For the most of the granite and the volcanic rocks after Nogene, the ratio between the geological interpretation unit and analytical unit is one to one. On the other hand, for the basement rocks and sedimentary rocks after Mesozoic, plural geological units are integrated in an analytical unit. Particularly in the areas with the distribution of basement rocks and sedimentary rocks, eight geological interpretation units were combined with two analytical units. In the areas with the distribution of sedimentary rocks from Miocene, ten geological interpretation units were combined with four analytical units. The following describes the characteristics each analytical unit and the distribution areas.

Analytical unit: Q

These units are in the sediment filling up alluvial soil, mainly consisting of alluvial soil

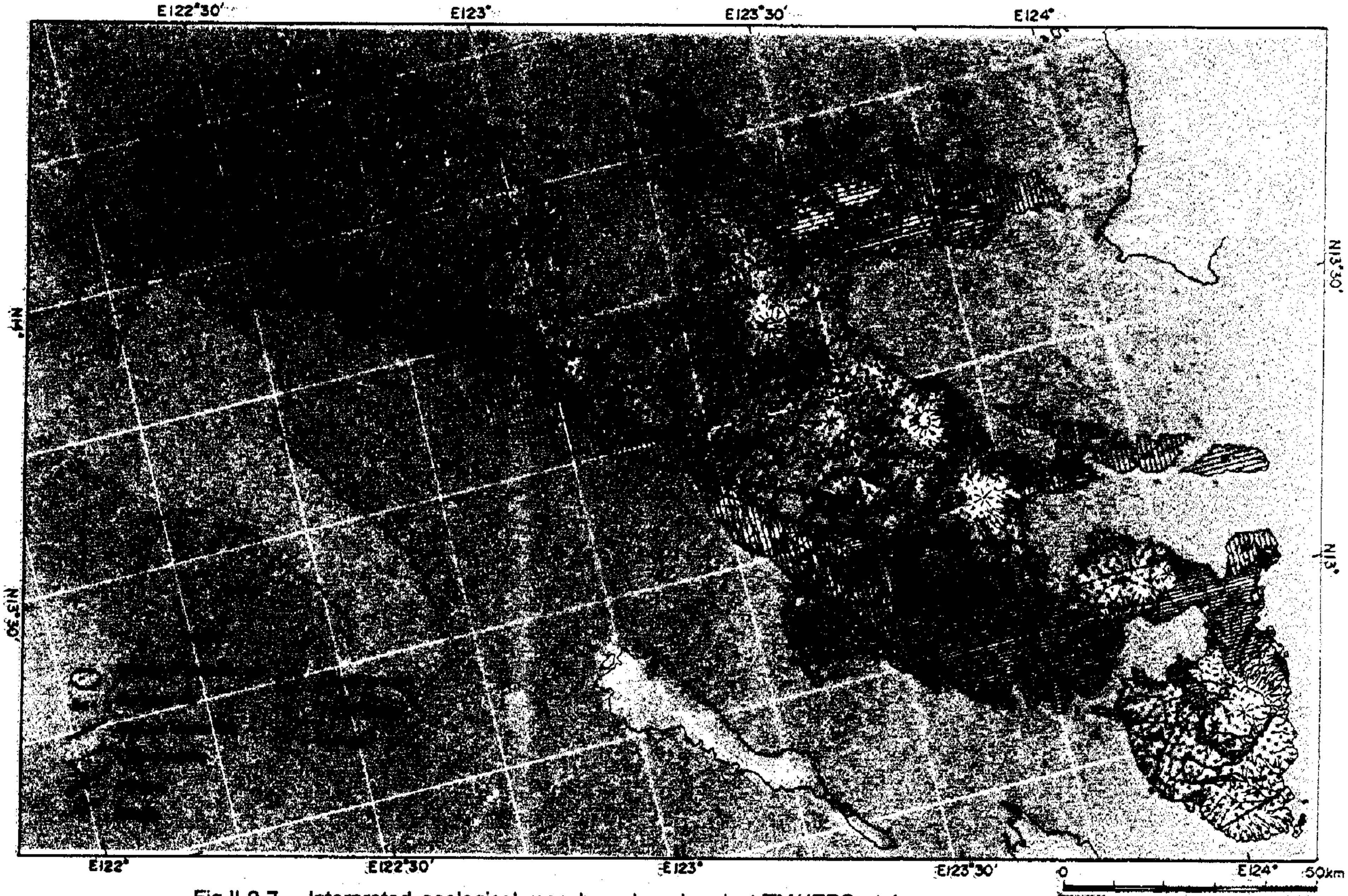
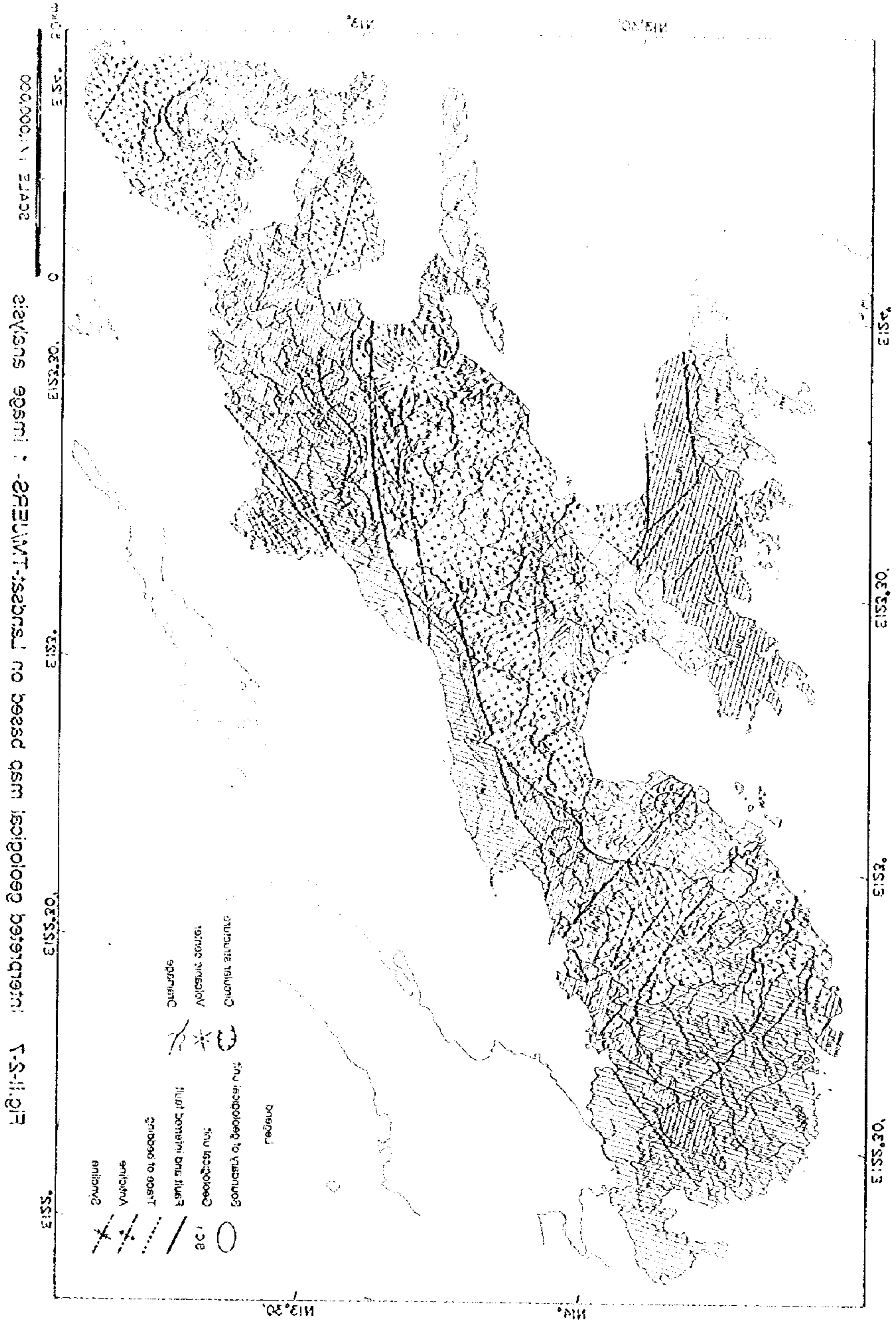
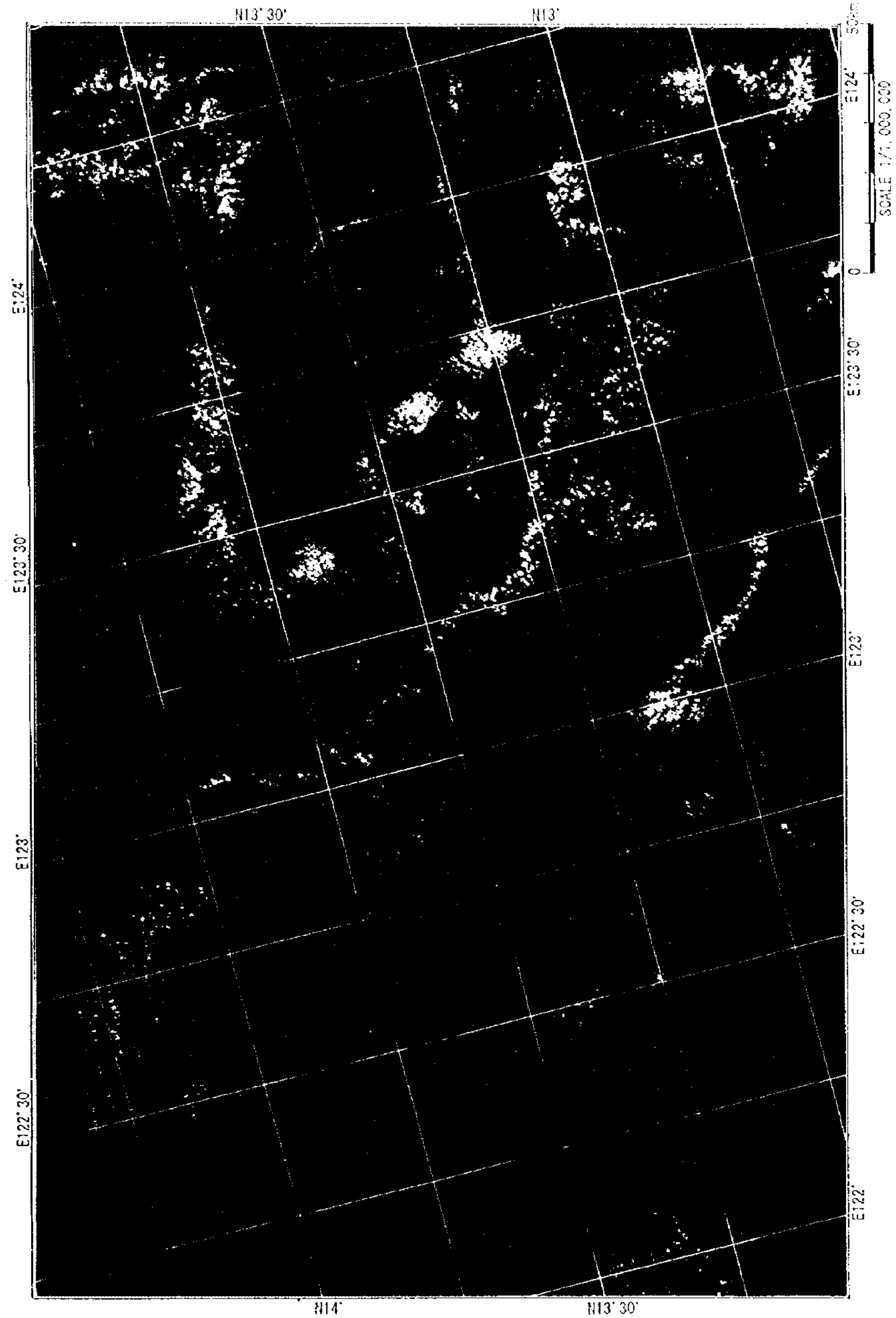


Fig.II-2-7 Interpreted geological map based on Landsat-TM/JERS- 1 image analysis





N13°30'
N13°
SCALE 1/1,000,000
0
50km
E124°
E123°30'
E123°
E122°30'
E122°
N14°

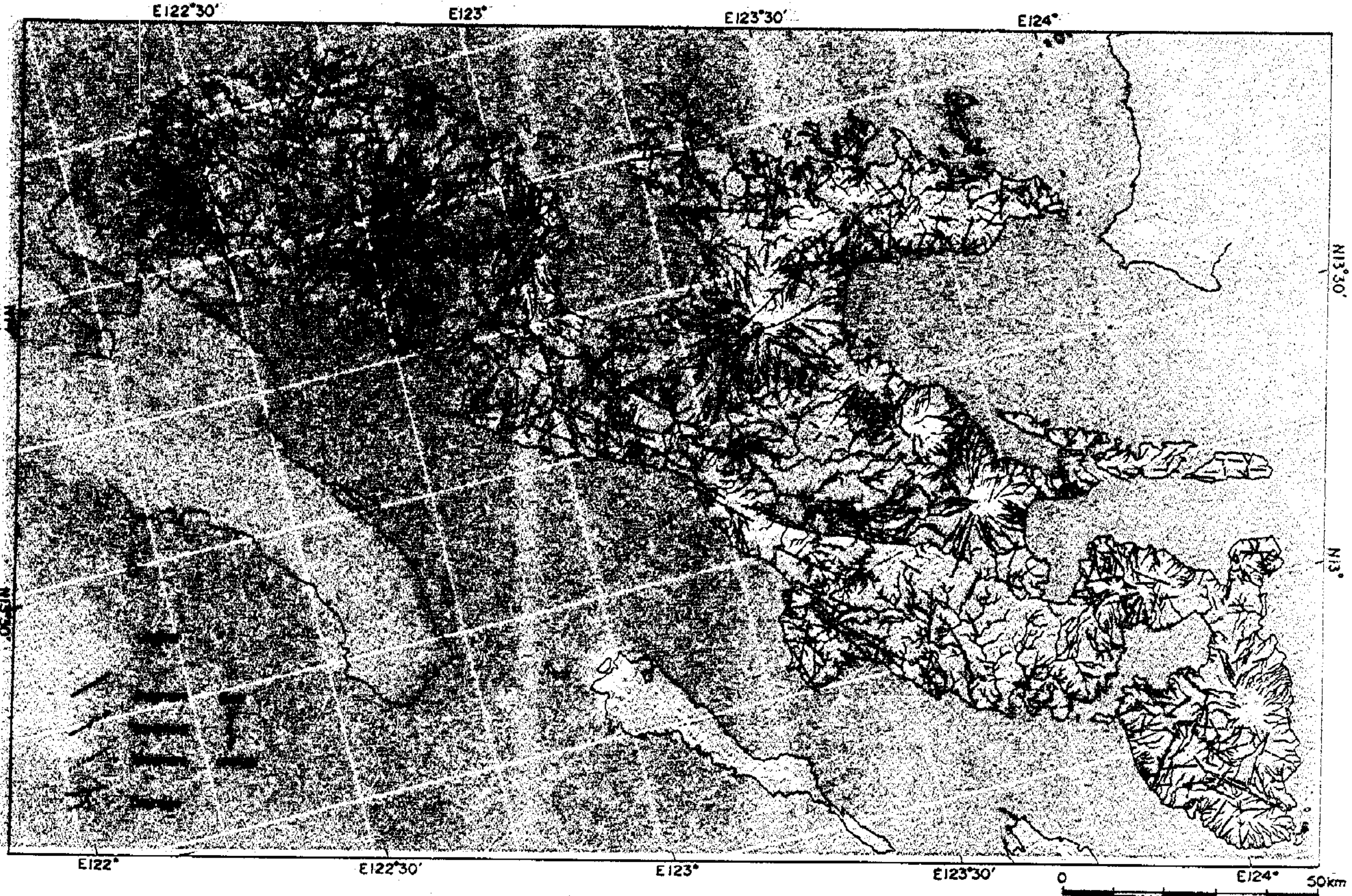
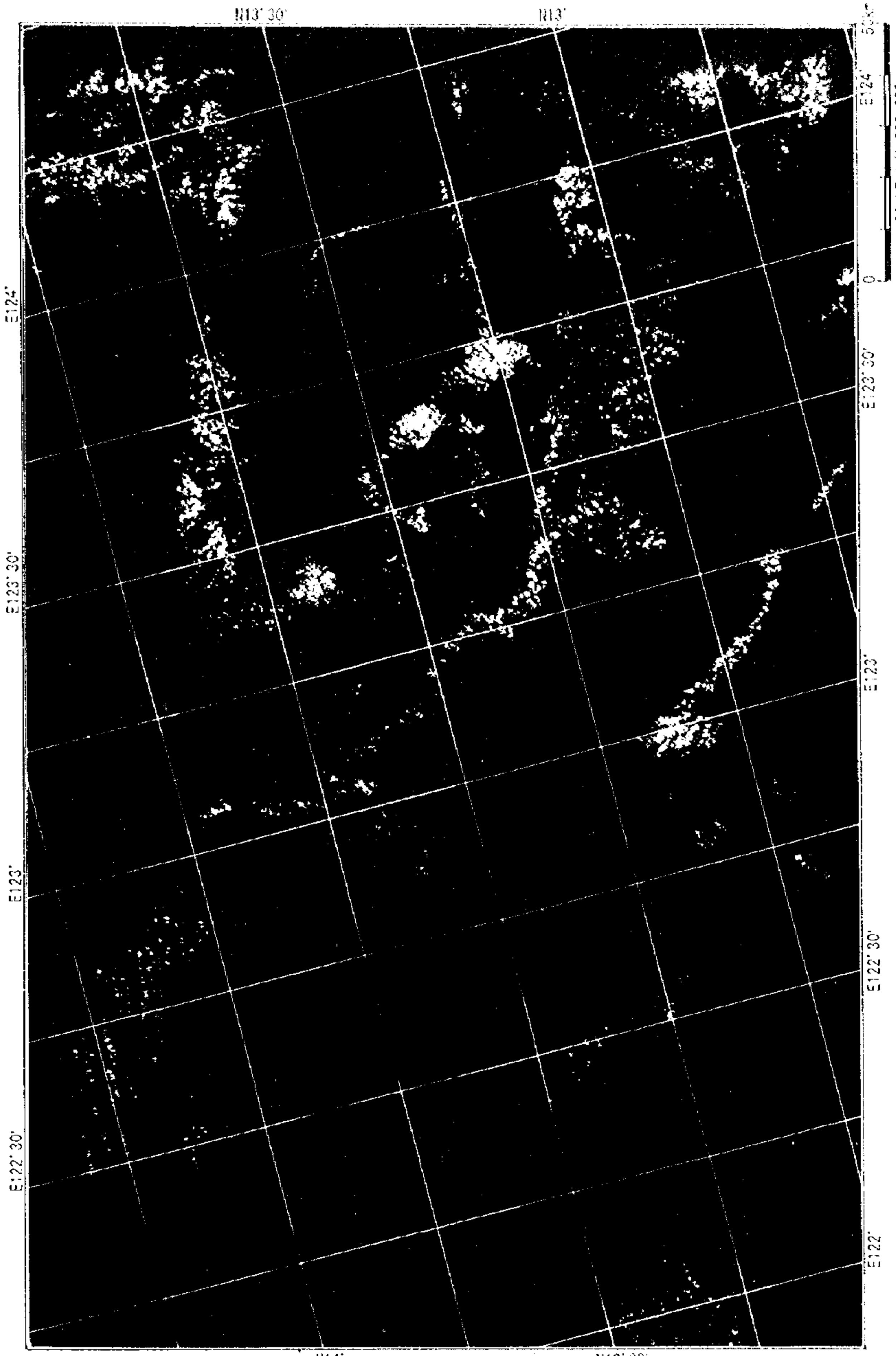


Fig.II-2-8 Distribution map of lineaments from Landsat-TM image analysis

Fig.II-2-8 Distribution map of lineaments from Landsat-TM image analysis



sediment, terrace sediment and that surrounding volcanoes from Quaternary. These are widely distributed at the center of Bicol Peninsula, and also dotted along the coast.

*Analytical unit: N**

These units are in marine and terrestrial sediment from Pliocene to Pleistocene, and classified into three analytical units according to the characteristics. N2 is the units showing the characteristics of reef limestone most remarkably. N1 is the units showing the characteristics of reef limestone partially and slightly. These units are distributed long and narrow west of Camarines Sur, west of Albay and north of Sorsogon in zonal distribution in order of N1, N2 and N3 from the southwest.

*Analytical unit: M**

These units are in marine sediment from Miocene to Pliocene, accompanied by tuff sediment, and classified into four analytical units according to the characteristics and distribution areas.

M1 is widely distributed westsouth of Queson, Camarines Sur to West of Albay along the southwest coast of Bicol Peninsula, positioned more southwest than N1. M2 and M3 are distributed west of Camarines Norte while M4 is distributed east of Caramoan Peninsula and in Rapu Rapu Island.

Analytical unit: Pg

These units are in sedimentary rocks and andesite lava containing the wacke and shale from Palaeogene, and distributed in Panganiran Peninsula, closely related to the following granitic rocks (Gr2).

*Analytical unit: BC**

These units are in basement rocks comprising hornblende picrite, cristalline schist and phyllite, in ultrabasic rocks and basic plutonic rocks, and classified into two types: BC 1 is distributed in the vicinity of Paracale in Camarines Norte, midwest of Caramoan Peninsula and Rapu Rapu Island, and positioned northeast of Bicol Peninsula, while BC2 is distributed near the boundries between Camarines Norte and Queson located northwest inland Bicol Peninsula.

*Analytical unit: V**

These units are in the volcanic rocks brought by the volcanoes in Quaternary, and classified into six analytical units according to the characteristics. V1 forms volcanoes with smooth surfaces, corresponding to Bulsan Volcano and those located west of Bacon. V2 corresponds to Mt.

Masatoga and Mt. Isalog. V5 corresponds to Mt. Cuylasi and Mt. Bintacan. V also corresponds to the pyroclastic rocks and collapsed sedimentary layers in the vicinity of the above said volcanoes.

*Analytical unit: NV**

These units are considered the volcanic rocks brought by the volcanoes in Tertiary, and classified into six analytical units according to the characteristics. NV1 is dotted in the vicinity of Parcale and on the skirts of Quaternary volcanoes located between Camarines Sur and Sorsogon. NV2 is distributed west of Sorsogon Peninsula. NV3 is distributed between Bacon and Manito. NV4 is distributed south of Sorsogon Peninsula and at the northwest end of Albay.

*Analytical unit: Gr**

These units are in intrusive rock bodies, and classified into two analytical units according to the distribution areas. Gr1 is distributed in the vicinity of Paracale, and Gr2 is distributed in Panganiran Peninsula.

2.2.3 Results of interpretation geological structures

As the geological structures, the bedding traces, fold structures, faults, circular structures and lineaments were read (Figure II -2-7). The following describes the results of each structure read. The lineaments will be described in the following Subsection.

(1) Bedding traces

The analytical units corresponding to the sedimentary rocks are N1 to 3, M1 to 4 and Pg described in the preceding Subsection. The bedding traces were partially read in these units. In M2 and M3 distributed in Camarines Norte, it is possible to trace the strata in the direction of NW to SE, but it is difficult to fix the down-dip. In M1 and N1 distributed along the southwest seaside between Camarines Sur and Albay, the strata are traced in the direction of NW to SE and N to S. These bedding traces are arranged in the form of echelons with the right-hand ends positioned higher. The strata are folded east to west by the fold structures in the direction east to west.

(2) Fold structures

The analytical units corresponding to the sedimentary rocks are N1 to 3, M1 to 4 and Pg described in the preceding Subsection, but the fold structures are read only partially in M1. In M1 distributed along the southeast coast of Albay, the bedding traces are folded from the direction N-S to E-W. The presence of synclinal axes in the direction NW to SE is conceivable.

(3) Faults

The presence of faults was presumed from the lineaments breaking the linearity and continuity between the geological interpretation units and from the lineaments accompanied by the variations in the drainage textures. Main directions of estimated faults are those trending NW to SE in parallel to the Philippine faults, and those trending NE to SW positioned diagonally thereto.

In the areas of sedimentary rocks distributed along the southwest coast located southeast of Bicol and in the boundaries (between Queson, southwest of Camarines Sur and southwest of Albay), the presence of estimated faults trending northwest to southeast is superb. On the other hand, in the areas with the distribution of volcanic rocks (Mt. Labo and Mt. Culasi in Camarines Norte, and the southern part of Sorsogon), the presence of estimated faults trending northeast to southwest is superb. In the areas with the distribution of basement rocks (Caramoan Peninsula) and the areas with the distribution of granite from Palaeogene (Panganiran Peninsula), the presence of estimated faults in the both directions trending northwest to southeast and northeast to southwest is observed.

(4) Circular structures

The circular structures observed are calderas and volcanic ones.

At the center of Sorsogon Peninsula, a circular structures showing calderas with a diameter of 15 km surrounding the half of Bulsan Volcano on the southwest side. In a part of the southwest portion, some spots show doubled circular structures. On the other hand, crater calderas are observed in Mt. Culasi, Mt. Isarog, Mt. Iriga and Mt. Malinao.

Volcanic features observed in order from the northwest are those of Mt. Labo, Mt. Culasi, Mt. Isarog, Mt. Iriga, Mt. Marinao, Mt. Masatog, a volcano located west of Bacon and Bulsan volcanoes (includin two on the western side). In the vicinity of these volcanic features, geological interpretation unist are distributed in an almost concentric circle.

2.2.4 Lineament Extraction

The lineaments in the both LANDSAT-TM and JERS-1/SAR images were read and extracted (Figure II-2-8 and II-2-9). The survey areas are clearly classified into two: one is with concentrated lineaments, and the other is with less number of lineaments. When these are compared to the analytical units, the areas with concentrated lineaments are those where volcanic rocks, sedimentary rocks, basement rocks and granitic rocks are distributed. On the other hand, the areas with less number of lineaments are those where alluvial soil sediment, collapsed strata around volcanoes and specific sedimentary rocks are distributed. The following describes the areas with concentrated lineaments.

The lineaments are distributed nearly in the whole areas located northwest of Camarines Norte, Queson and Camarines Sur. Among these areas, those with extremely concentrated lineaments are as follows: West of Camarines Norte to Queson: In this area, the lineaments trending NW to SE, NE to SW and N to S are superb in the area where the sedimentary rocks (M1 to M3) listed as the analytical units (hereinafter abbreviated) and granitic rocks (Gr1) are distributed. In the area where the volcanic rocks from Mt. Labo (V3) and the same from Mt. Culasi (V5) are distributed, located east of Camarines Norte to northwest of Camarines Sur, the lineament trending NE to SW are superb, accompanied by those trending NW to SE and N to S.

In Caramoan Peninsula located northwest of Camarines Sur, the lineaments are distributed throughout this area. However, particularly in the area where the basement rocks (BC1) yielded from the center of the peninsula are distributed, the lineaments trending NW to SE and NE to SW are concentrated.

The lineaments trending NW to SE and NE to SW are superb in the area where the volcanic rocks from Mt. Isarog and Mt. Masatoga (V2), the same from Mayon volcanoes (V4) and the same from the vicinity of Buhi (NV4) are distributed, along the middle of Camarines Sur to the northwest of Albay, accompanied by the lineaments trending NNW to SSE and NNE to SSW. Also in Rapu Rapu Island, the lineaments trending WNW to ESE and ENE to WSW are distributed.

The lineaments trending NW to SE and NE to SW are superb in the area where the sedimentary rocks (N1 to 3, M1 and Pg) are distributed, in the direction southwest of Camarines Sur to northwest of Sorsogon via west of Albay.

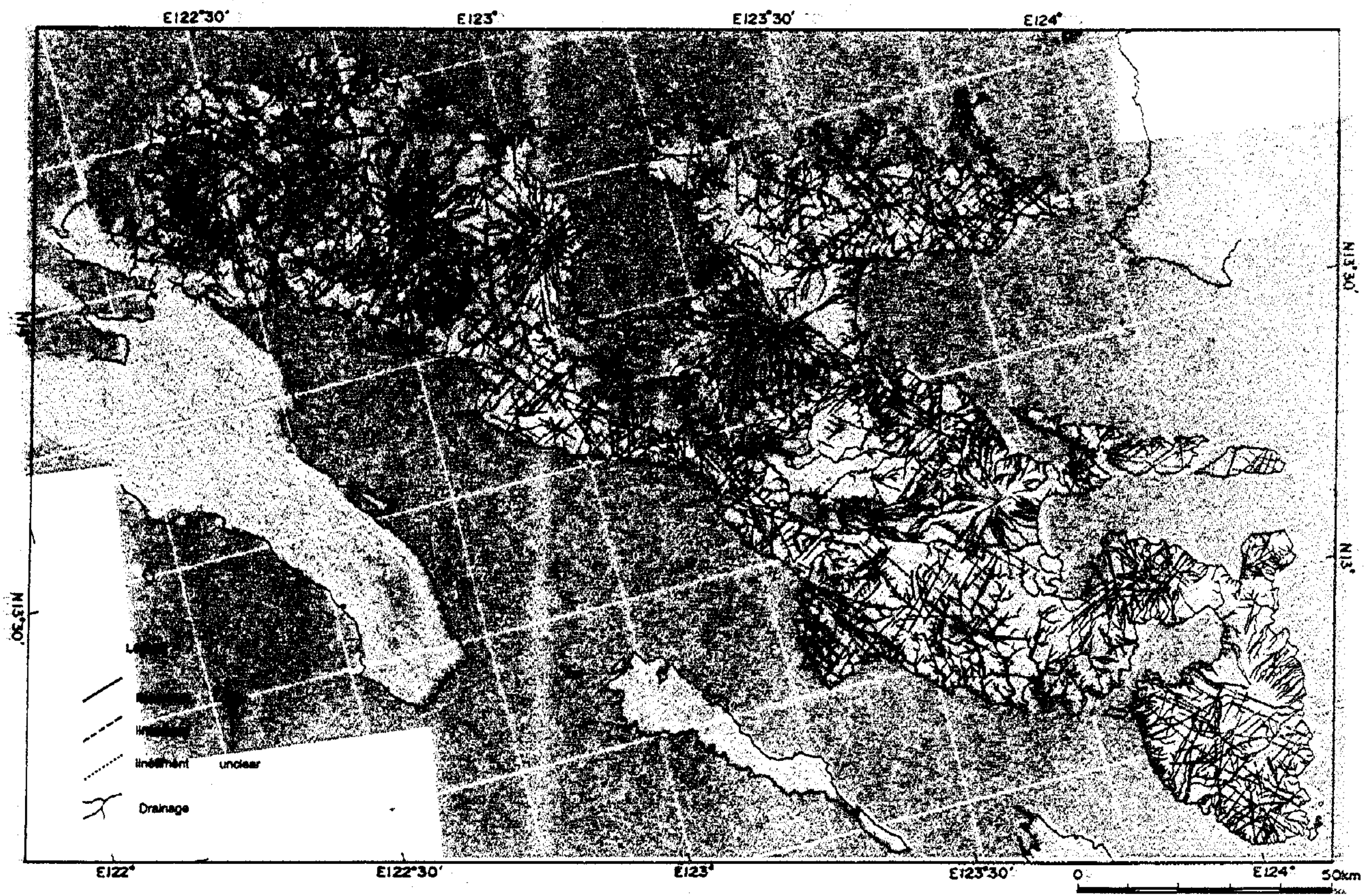


Fig.II-2-9 Distribution map of lineaments from JERS-1/SAR image analysis

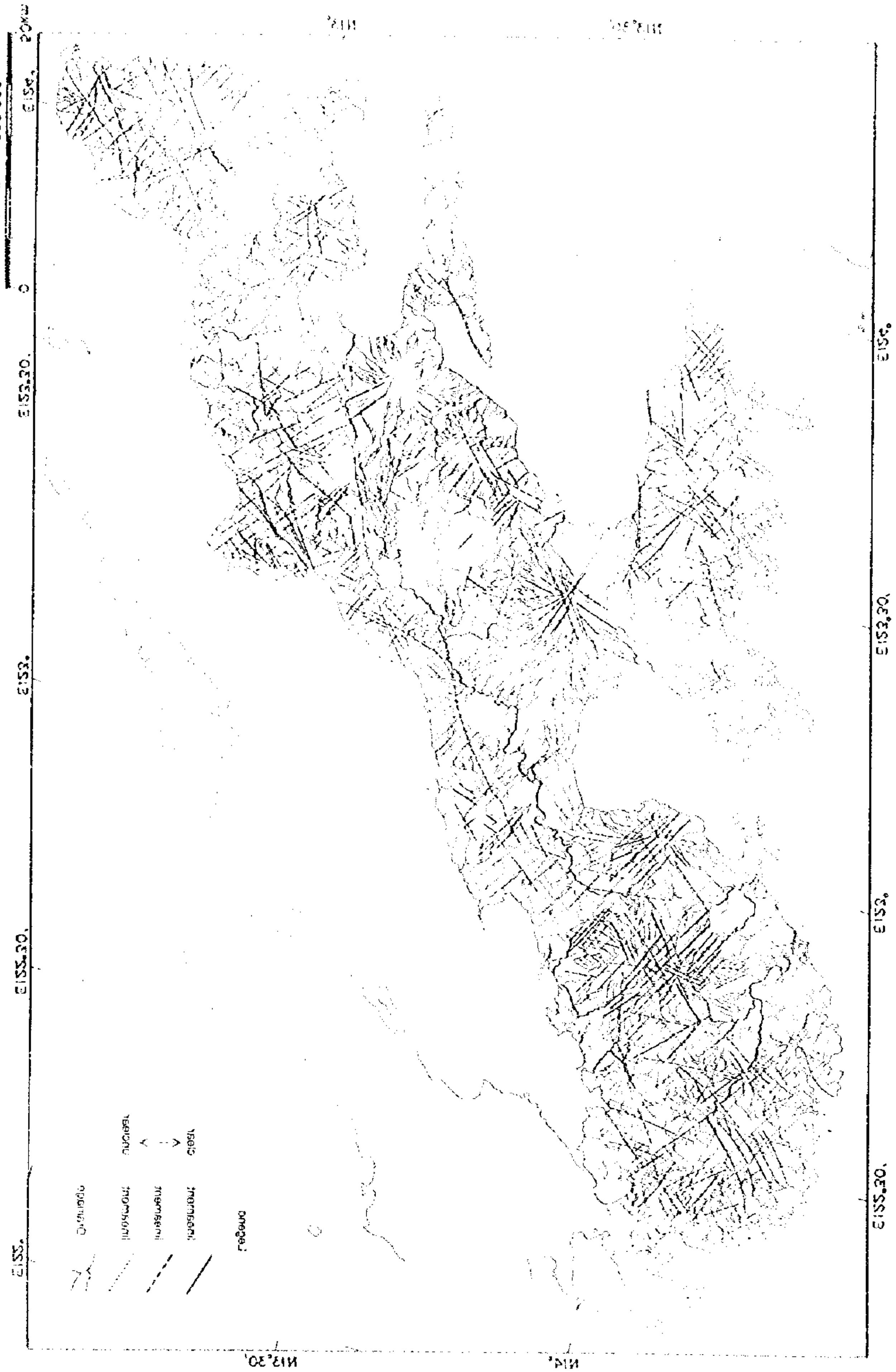


Fig.II-2-6 Distribution map of lineaments from JERS-1/SAR images analysis