Discovery of a new mineralized area in Lomblen Island of Indonesia indicated by the remotely sensed image data

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Abstract : A new mineralized area was discovered in Lomblen Island of Lesser Sunda Islands, Indonesia, through the process of digital image analysis of LANDSAT-MSS and SPOT data. The key indicator is the ring structure which suggest the cauldron or dome system to produce a good environment of mineralization by the fracture system and the heat source of the hidden magmatic activity. The ring structure shows a polygonal or circular in shape which is clearly detectable in the well processed image. One big circular structure in the northeastern part of the island is detected in the enhanced image data. The surface ground investigation was made to clarify that there exist the silicified rocks with quartz vein in the marginal area inside and outside of the ring structure. Lead and zinc mineralization was once detected in the north part of the ring structure. There are two known barite deposits, one of which is associated with silicified volcanic rocks containing 28 to 86 g/t of gold. The barite ore contains about 1% of strontium (celestite molecule). Since the island is covered by Neogene to Quaternary volcanic products, it is predicted that there will be the gold mineralizations along the other ring structures in the island.

I. INTRODUCTION

The recent development of the modern industries in many countries in the world lets them increase the demand for more industrial materials. The present world supply of natural minerals seems to have no difficulty in production, though several scenarios have been sounded that the mineral resource crisis like the oil crisis in 1974 will happen after two or three decades. Although we do not know whether it is true or not, the natural mineral resources are the non-renewable resources. If we stop the effort to seek the new frontier of mineral resources, the unhappy result will come belatedly when the exploration will never be able to put into practice of the quick production for natural materials; i.e., there is a long lead time to develop mining. The demand of exploration should precede long time before the demand of exploitation for natural mineral resources. We need the precise geological informations for the precision exploration.

In many areas where the geological investigation has not been well processed, we have to be confronted with the lack of the data and the inferior conditions of the transportation, housing, meal, medicals, and so on. There are many regions left in the world where we do not have good informations of geology, geochemistry, geophysics, and the history of mining. The underground data which we really need are moreover difficult to take from such regions. Historically saying, mining industries spent much effort of surface investigation earning for geological, geochemical, and geophysical data with much long time. Using new and advanced technologies developed recently, we can decrease the wasted effort for the long and high-cost investigations. The remote sensing is one of the new technologies to recognize the investigation area widely and estimate the deep structures.

Several different land-observing satellites are recently available; LANDSAT, SPOT and MOMO. The data from the satellites have the following features;

(1) Synchronous (at the local time during 9:30 - 10 : 30),
(2) Wide scale area observation ,
(3) Repeatability (every 16 or 18 days), and,
(4) Multispectral bands.

One disadvantage is the relatively low resolution (79m x 79m for MSS, 50m x 50m for MOMO, 30m x 30m for TM and 20m x 20m or 10m x 10m for SPOT).

Using the above, we can make the low-cost and quick investigations for the new and unknown frontier of geological area. The Lomblen Island of Lesser Sunda Island in Indonesia is one of the target where the past activity of geological investigation has not yet well processed and the mineral resources are probably expected. The Geological Survey of Japan and the National Center for Geotechnological Research and Development of Indonesia have jointly developed the integrated method of investigation for the difficult surveying area, the typical target of which is the Lomblen Island (Fig.1). We use the LANDSAT-MSS and SPOT images to make the initial geological map. Through the analytical procedure of digital processing of remotely sensed image data, we discovered the peculiar ring structure there. According to the surface investigation in short time, we found the ring structure of caldera-like volcanic area with some mineralized veins. This paper describes the method and the application for the unknown geology using remotely sensed image data.

II. METHODS TO USE THE REMOTELY SENSED IMAGE DATA

[1] Detect the linear structure

The linear patterns from satellite images are not the same as linear topographic features on surface landform, though linear features on the surface are reflected in the linear patterns of images. The pixels relation method (Kouda et al, 1985) extracts linear patterns from satellite images and is defined as the arrangement and relationship between each pixel, which corresponds to the resolution of the satellite image.

The principle used to extract linear patterns from satellite images is based on the pixels relations which consist of five types:

(1) lines reflecting shore lines, ranging hills, and valleys,
(2) bright or dark lines or parallel lines of darkness and brightness,
(3) lines linking elbows of zigzagging lines of types (1) or (2),
(4) lines linking isolated points or edges of lines and continual lines of types (1) or(2),and,
(5) lines with large widths of pixels.

The lines of types (1) and (2) are uniquely defined only in images with high reproducibility. We call this method of extracting linear patterns the pixels relation principle. The significance of the linear patterns from satellite images can be divided into six classes as follows:

1) artificial structure,
2) boundary between water, land, and ice,
3) boundary of different rock facies,
4) line of ranging hill and valley,
5) other geologic structure, and,
6) image noises.

We do not adopt the class 1), most of the class 2), and the class 6). Linear patterns without geological significance should carefully be eliminated so that the final result has the geological meaning, some of which reflect deep structure.

The next step is to search for polygonal patterns in volcanic fields. Before describing it, we shall consider volcanic structures. For example, for epithermal gold deposits, several MSS images were studied from which we extracted linear patterns through digital processing(Kouda et al., 1986). Comparing the enhanced results and verified by SLAR image, air photos, geomorphological maps and field survey, it was suggested that many linear patterns are visible and confirmed by ground truth, and that some of them are polygonal in shape. It is assumed that these linear patterns are associated with deeper structures in the earth's crust. For example, the inner and outer shape of the Quaternary Kakuto caldera depicts a hexagonal pattern both in linear patterns and in land surveys. This caldera is strongly associated with the newly found big gold deposits, the Hishikari Mine. Recent Ebino earthquakes are considered to be due to deep activity of the Kakuto cauldron (Aramaki, 1968). Consequently, it is suggested that some linear patterns which are polygonal in shape reflect calderas on the earth's surface or unexposed cauldrons which is probably related to the epithermal deposits(Kouda & Koide, 1978).

[2] Classify the textural domain

There are many methods to depict the image textures. In the case of application to geological fields, the most important criteria to choose the textural analysis method is the significance of the geological process. Surface smoothness and roughness are reflected in the textural feature in the image.

Smoothness and roughness are the surface morphology and generated by the difference of the geology and the erosional process. The frequency distribution of hills and valleys consists the density distribution of image brightness because the surface morphological feature is mostly composed of the degree of angle and wideness or length of the surface slope which shows various reflectance by the directional projection of sunlight. There is the advantage to compare the wide area at once since the land-observing satellites synchronously take the image at once. So that the distribution of brightness and darkness in the image has the significance of the surface texture.

We use the standard deviation method (S.D.) to detect the density scattering of image; i.e., the extension from the second degree moment of the density distribution. Smooth sedimentary rocks and old volcanic rocks can be distinguished through this method, for example. In order to do this, the SPOT panchromatic image (87.8.9. scene 320-367) was processed because of the highest surface resolution (10m x 10m).

[3] Spectral features

The target area is strongly covered by the vegetations. Most of the remotely sensed image data show the strong reflex of near infrared spectra which means the thick and widely appearance of chlorophylls. Most of the outcrops of rocks or soils are hidden by the vegetations. It is, however, not true in the dry season when the vegetations tend to wither so the scenery there looks like the savanna desert. Some outcrops can be seen in the image data as a small spot where sometimes corresponds to the characteristic rock region like alteration zones. The small spot consists brighter spectra for MSS band 4, SPOT band 2, or MOMO band 3. In order to set up the surface investigation efficiently, we can pick it up as the target to survey. If we get longer wave image of infrared region or the data of higher spectral resolution we can discuss the nature of outcrop more in detail.

In this paper, we only use the small spot detection for the spectral features. More detailed study on the spectral features will be reported in the next paper. Our method of remote sensing is systematized one integrating above three categories.

III. LINEAR PATTERNS AND THE IMPLICATION OF CAULDRONS

[1] Linear patterns of Lomblen Island

From the result of the linear pattern analysis of SPOT image in the east part of the Lomblen Island, there are at least two distinctive ring structures which suggest the volcanic cauldron in the older age(Fig. 2).

The structural map informs lineament and curvilinear lines indicating fault and fracture distribution in the island as well as the ring structure associated with possible caldera rims. Plotting the lineaments into rose diagram shows 5 dominant trends in N 50-70 E, N 30-40 E, N 0-10 W, N 20-40 W and N 50-60 W, directions. The fracture pattern is coincide with the regional structural pattern developed from a northward compressive stress.

Lithologic map derived from the interpretation of remotely sensed data has been able to update the existing preliminary geological map. Distribution of volcanic products could be well delineated especially for those of young volcanic bodies. The morphological expressions are very peculiar compared with the sedimentary rocks and old volcanic units. Moreover, it is postulated that the old volcanic units, which are assumed to be young Tertiary of age, are still confined to certain volcanic bodies, judging from the structural pattern distributions.

[2] Cauldrons

The surface fracture system in the volcanic region strongly depends upon the shape of the magma and its ascent path. It is necessary for epithermal type deposits to be generated through the volcanic fracture system which arises from the magmatic upward movement. Hydrothermal solutions may move through the fracture system. The shape of volcanic fracture systems is not only of ring fractures associated with calderas, but also of radial fractures associated with calderas and domes, and of straight fractures of rifts.

We estimate five or more cauldrons in Lomblen island according to the ring structures and the distribution of the Neogene volcanic rocks. The shape of the ring structures are partly polygonal and partly circular in the SPOT image. The northern ring structure (R1 in Fig. 2) has the volcanic walls in the outer shape with the bimodal volcanic intrusions. Ring fractures can be seen in the figure 2. There occur NW-SE directed parallelly linear lines inside in the ring structure which suggest the central fracture swarms which frequently happen in many present active calderas (Koide, 1978). The ring structure R1 elongates to NW-SE direction which reflect to the deep magma shape. This direction crosses to the general direction of the island of NE-SW and also to that of the Lesser Sunda islands of ENE-WSW.

Other cauldrons are still hypothetical because we have not yet investigated the other areas of Neogene age. They, however, possibly exist according to the image analysis.

IV. TEXTURAL DOMAINS AND THE GEOLOGICAL MAP

The S.D. value is strongly influenced by the window size for the digital processing. It depends upon the size of textural domains in the image. In this case, the size is so small that we should take smaller 32 x 32 bits window operator to calculate the statistical values in it. 64 x 64 window does not distinguish each domain because this window include two or three domains of texture. The value itself has no meaning. Comparing the value among some domains in the same image is only significant.

Under the result from 32 x 32 window, we can divide five classes for each 1.5 step from 1.5 to 9 of S.D. values. The smallest S.D. value of 1.5 - 3 that is of the smooth area depicts the younger age of coral reef and active volcano, which locate in the coastal area in the island. The second smallest S.D. value of 3 - 4.5 is of also smoother area of younger volcanics in the inner region. The intermediate S.D. value of 4.5 - 6 is of rather rough surface where late Neogene volcanic rocks occur with the ring structures. The second largest S.D. value of 6 - 7.5 is of Neogene volcanic rocks, where the ambiguous ring structures can be seen. The largest S.D. value of 7.5 - 9 is of the youngest volcanic area where the activity of volcano is continued to date. In this area, some parts of the surface are rather smooth especially in the northeastern flank of the Paugora volcano, the north of which there occur the dangerous land slide happened in 1979. The outer circle of the crater and surrounded flanks seem so rough in texture that the S.D. value goes so high. Again, the absolute values of S.D. do not have the general significance of geology. This area has the older Neogene rocks in the underground and covered by the youngest volcanic ash and rocks on the surface. The volcanic activity in this area is so young that it is interpreted that the covering volcanics on the older rocks do not become so thick to make the surface smoother.

According to the structural and textural study, and also to the surface investigations, we can set up the first geological map of Lomblen Island in very short time(Fig. 3). Although the detailed nature of each rock facies can not be detected by remote sensing method, we can proceed the structural interpretation for mineral resource exploration based on the map and remotely sensed image data.

V. DISCOVERY OF THE MINERALIZED AREA IN THE NORTH ERN CAULDRON

There are some evidence that the distribution of mineralization in the eastern part of Lomblen is controlled by a huge fracture system. Mineralizations observed in the field are barite ore, Cu, Pb, Zn ore, gold bearing silicified rocks.

In the inner southeastern part of the ring structure R1(Fig. 2), we have the small barite deposits in Atanila which contains 1% of strontium and 0.2 ppm of silver in a hand specimen. Since we can confirm the presence of silver, it may be the same type of the north eastern unnamed barite-gold deposits, which contains 28 to 86 ppm of gold in it. The southwestern part of the ring forms much disturbed feature where the structural and volcanic activity are considered to be very intense. In opposite side from the Atanila barite deposits over the disturbed area to the southwest, we discovered a new occurrence of quartz veins in the altered felsic volcanic rocks. This area shows bright spot of spectra in the SPOT image. One small sample of quartz vein with sericite contains 2 ppm silver, but trace of gold. This area of quartz vein is a little bit far from the strong line of ring, so it is suggested that this area is the peripheral margin of the zonal gold mineralization area. It is also suggested that we should make the surface investigation more around the ring carefully, because the ring structure suggests the newly discovered mineralized area which is most significant in the first stage of prospecting.

In case this geological control is correct, there may be another prospect areas in the Central Lomblen Island since other ring structures are also distinctively observed in several places.

VI. ACKNOWLEDGEMENT

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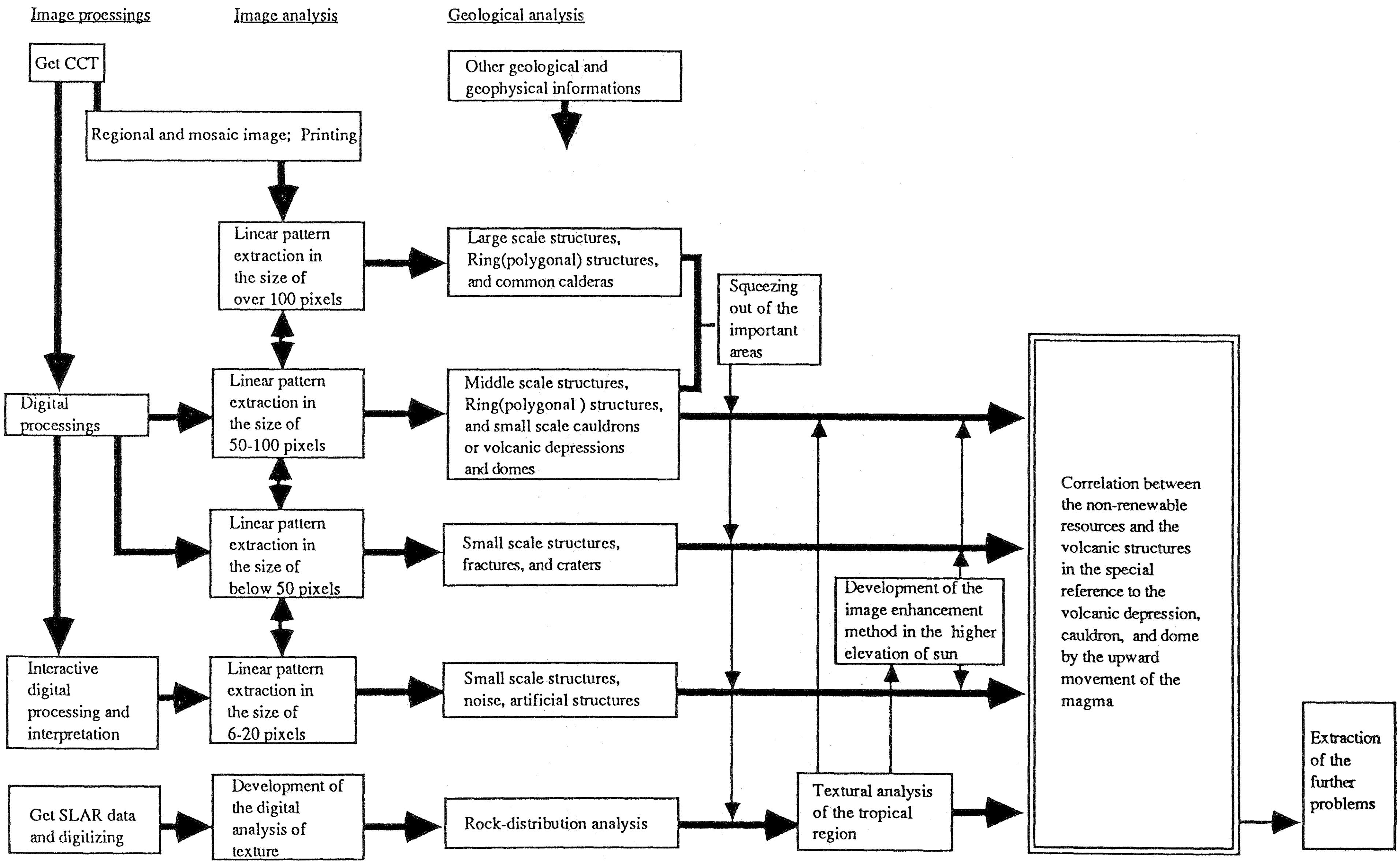

Figure 1 Research method of the remote sensing exploration for the non-renewable resources.

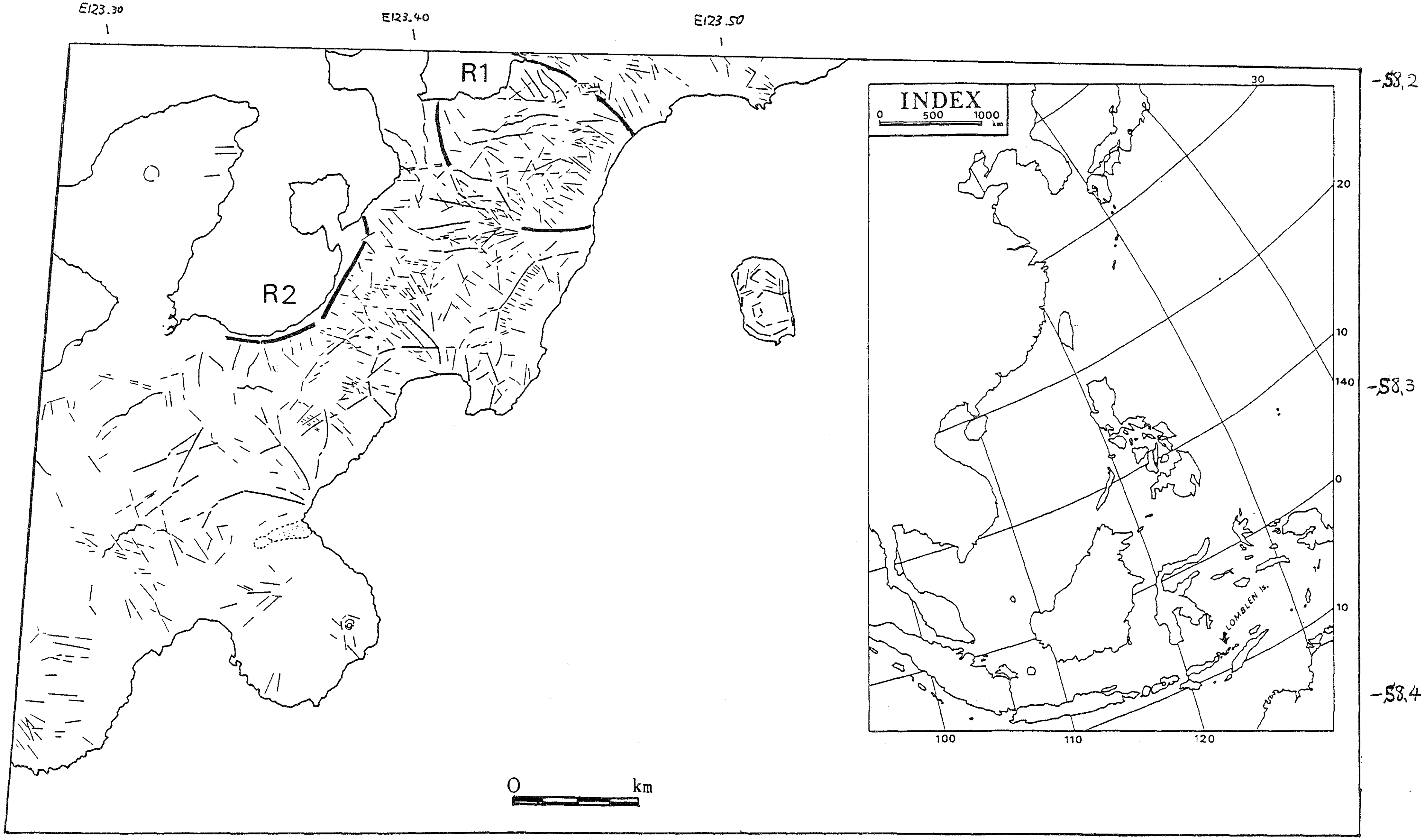

Figure 2 Linear patterns of the northeastern Lomblen Island with two distinctive ring structures (R1, R2) extracted in the SPOT image.

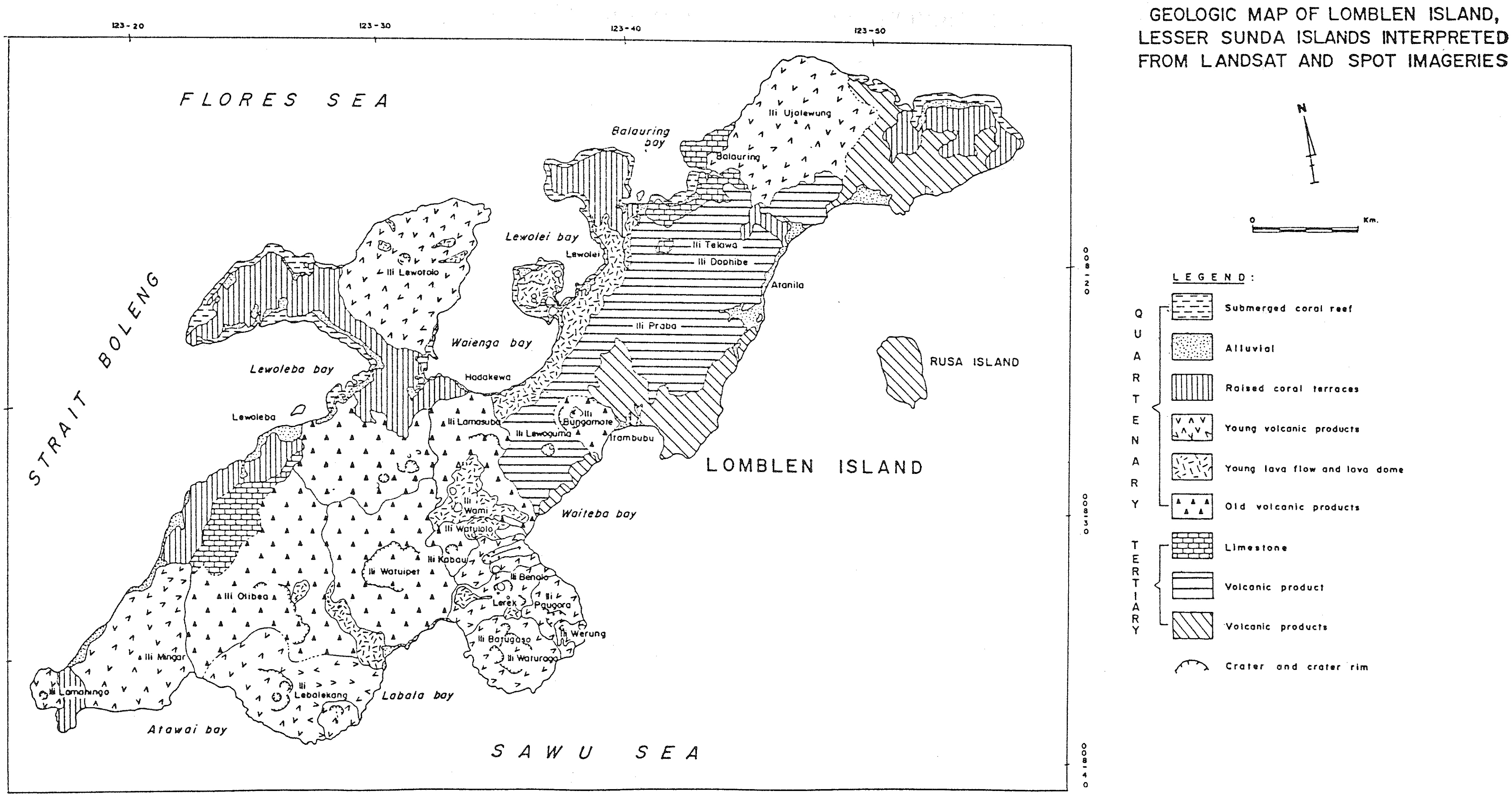

Figure 3 "Remotely sensed" geologic map of Lomblen Island.