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Digital Geological Mapping using ASTER Level-1B in Relation with Heat Source of Geothermal System in an Active Volcano

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ABSTRACT

There are many difficulties to create geological map details in an active volcano. The main difficulty comes from hard terrain condition to be reached which is related to the higher cost of field mapping activity. In this research we tried to solve the problem simply using optical remotely sensed techniques. The objective of this study is to recognize the volcanic materials distribution and its relation with subsurface structure condition controlled the study site. The ASTER (Advance Spaceborne Thermal Emission and Reflection Radiometer) images as an optical sensor were used in this study. Therefore a field observation assisted by petrography study was also used to validate the results. The spectral analysis of the rock samples also applied to discriminate between the fresh rock and altered rock. On the other hand, we also adopted a 3D tomography data analysis to obtain the subsurface condition beneath study site. We chose Guntur volcano situated in West Java-Indonesia as study site. This active volcano is located inside Guntur complex, which is a volcanic chain distributed along a northwest-southeast trending belt. The results showed the lithology of Guntur volcano which is covered by volcanic product such as lava, pyroclastics and lahars. Most of lava deposits were altered and characterized by existence of several alteration minerals such as chlorite. The spectra of altered rocks increase relatively in the visible to short infrared range (0.4-2.5 μm). On the contrary, the spectra of the fresh rocks increase in visible range (0.4-0.8 μm), but decrease in the short infrared range (0.8-2.5 μm). Detecting the altered rock zone is an important point in relation with the heat source of geothermal system. Based on seismic tomography analysis the heat source of the geothermal system in the Guntur volcano is located beneath the crater about 2-4 km under the sea level. The heat source generated the geothermal system in which surface manifestation detected by ASTER image analysis. This study can be used for geothermal exploration and fast geological mapping in an active volcano.

Keywords: geological map, ASTER, Guntur, spectral, tomography

1. INTRODUCTION

Geological map generally provides of earth surface information including rock type (lithology) and geological structure controlled the area. The map is usually made by the geologist in a geological field activity. However some areas are difficult to be reached mostly in the volcanic terrain. Dangerous gases from the crater or deep ravines sometimes hamper the geologist to map the rock distribution of the field study. In this paper we applied the remote sensing techniques due to possibility to solve the problem even though using the optical sensor which is usually inferior compared with the other sensor such as microwave sensor.

The aim of this study is to recognize lithological units digitally using ASTER images and their relation with subsurface condition such as potential of the heat source or magma location. The ASTER data have been widely used as a powerful tool for geological mapping because the ASTER images can discriminate quartz and carbonate rocks as well as mafic–ultramafic rocks (Ninomiya et al., 2005). The ASTER images were analyzed after FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) atmospheric correction, a module of ENVI software. Besides the ASTER data, we also used the SolidSpec-3700/3700DUV spectrometer which uses a wavelength ranging from 0.4-2.5 μm to obtain the spectral characteristics of rock samples. On the other hand, the polarization microscope was used to obtain the mineral content based on its optical properties. Combination technique between spectroscopic and microscopic analyses can be used to discriminate rock properties, such as alteration mineral contents accurately.

Guntur volcano was chosen as study site (Figure 1). This volcano is one of 35 the most active volcanoes in Java, Indonesia, located inside Guntur Complex, which is a volcanic chain distributed along a northwest-southeast trending belt. Guntur Complex is part of an evolution of active volcanoes covering large area where one of the centers of its magmatism, that is Kamojang Crater, is a geothermal field that has already produced electricity. The last eruption was occurred in 1840 with new volcanic product covering the eastern part of the volcano.

2. DATA SELECTION AND METHODOLOGY

2.1. Data Selection

ASTER (Advance Spaceborne Thermal Emission and Reflection Radiometer) is a sensor onboard Terra Satellite observing the earth in altitude about 705 km from surface (Abrams and Hook, 1998).

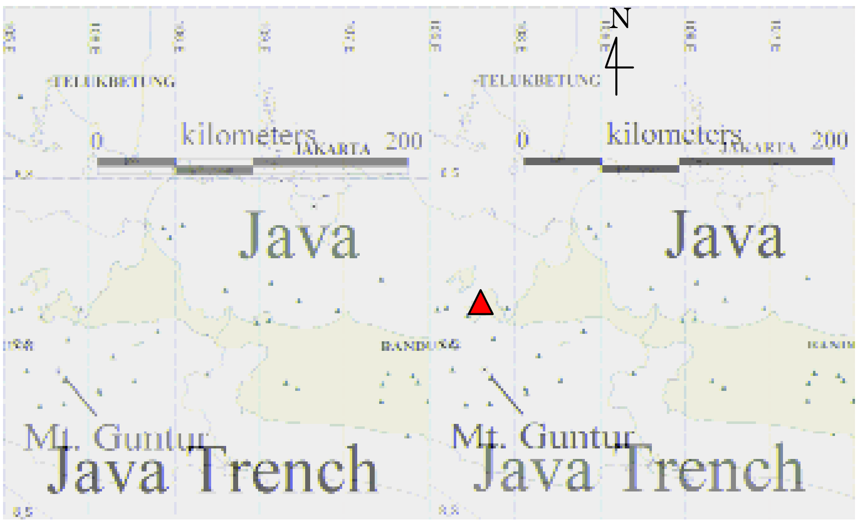

Figure 1. Guntur volcano depicted on volcanic distribution map of West Java.

The function of the sensor is to record the object on the earth surface which used wavelength ranged from the visible near infra red to thermal infrared. An ASTER level-1B radiance at-sensor data consists of fourteen bands which are divided into three types VNIR (Visible Near Infrared Radiometer), SWIR (Short Wavelength Infrared Radiometer), and TIR (Thermal Infrared Radiometer). We focused on VNIR sensor due to the high resolution (15 m) and its wavelength ranges correspond with the range of SolidSpec. Time selection of ASTER data with clouds coverage less than 5% coverage area makes the target area shown clearly. The high resolution image with lack of vegetation and cloud condition can be used for detail mapping of volcanic distribution.

2.2. Methodology

The main target of the ASTER image processing technique is to detect geomorphology and lithological unit. Each unit was distinguished based on different tone, texture and structure on the images. The surface condition detected by ASTER image analysis then synthesized and correlated with subsurface condition from tomography analysis. The correlation between surface and subsurface condition can be used to trace the geothermal system in a volcanic active setting. Work flow of methodology is shown in Figure 2.

The first step in ASTER image processing is image calibration which is divided into two types, that is geometric correction and atmospheric correction. The geometric correction is only applying the geometric position from header file. This process aligns the images to the north direction (Geo-coding). The atmospheric correction was applied to remove gases and small particles effect in the atmosphere. The FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) atmospheric correction, a module of ENVI software was adopted to omit the effect from atmosphere condition which frequently interfere with interpretation process. Thus, this correction is an important step to be always performed.

The next step after image calibration is image enhancement, filtering and classification. The purpose of those image processing is to delineate features of the object recorded at surface provided by the ASTER images. After image processing performed, the step was continued with field observation. By using remote sensing technique, only some interesting points are needed to be sampled. The information from the field observation included boundary of lithology unit, geological structure, lithological type, and correlation of each lithological unit (stratigraphy). Some rock samples were carried out to the laboratory to be analyzed. Each sample location is coded and the coordinate is acquired by using a handy Garmin GPS.

The laboratory analysis comprises petrography analysis employing polarization microscope and spectral analysis employing SolidSpec spectrometer. On the other hand, seismic tomography with three-circle intersection method was applied to determine the hypocenter. The hypocenters resulted by this method were then relocated by using a 3D velocity model from a non-linear tomography inversion. This seismic tomography analysis used to estimate the subsurface structure controlled the volcano mainly for predicting the magma chamber location and its relation with the altered zone at the surface.

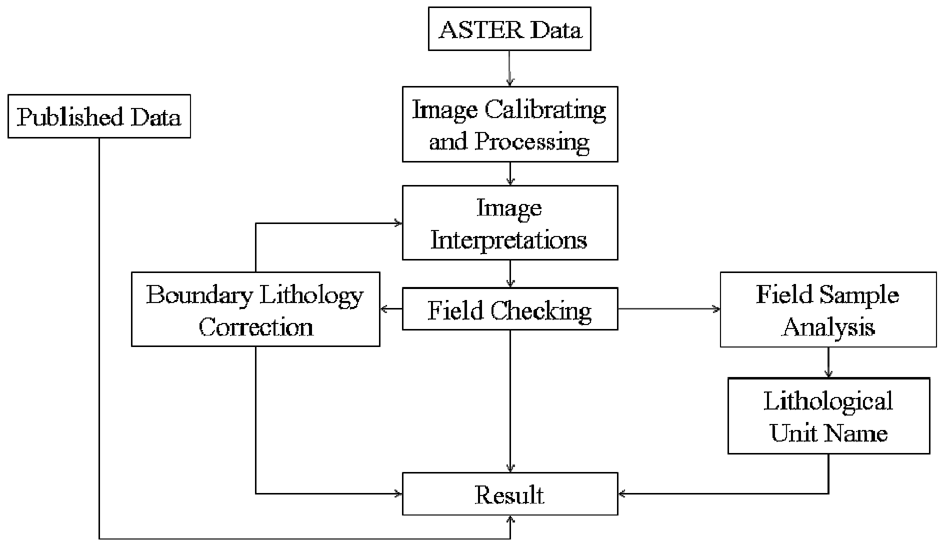

Figure 2. Flow chart of methodology.

3. GEOMORPHOLOGIC DELINEATION OF GUNTUR VOLCANO

The first step in interpreting the ASTER image is to delineate the geomorphologic units. These units are defined by similar shape or structure imprint in the ASTER images and then presented as a Geomorphologic Map. This map is used to support the lithological boundary identification in the field observation stage.

Generally, there were two geomorphologic units detected in Guntur volcano, called as Guntur product and Outer-Guntur product. Guntur product is a geomorphologic unit where the materials originate from Guntur volcano. This unit is characterized by flow impression on ASTER image and it is distinguished by Outer-Guntur product that showed sculpture structure (see Figure 3). The materials of Outer-Guntur product are composed by others volcano surrounding the field study and characterized by sculpture impression structure. This structure was caused by long erosion which resulted galleys and ravines (Suwijanto, 1990), implied that the Outer-Guntur product should be older than Guntur product itself.

The differences between Guntur product and Outer-Guntur product also detected using Normal Differences Vegetation Index (NDVI) method (Figure 4). The Guntur product is characterized by low NDVI value caused by rare vegetation. However the NDVI value of Outer-Guntur product is higher than Guntur product because of existing of dense vegetation. Weathering process is more intense occurred in Outer-Guntur product because old volcanic rock type changes easily to be volcanic soil. Therefore, the vegetation is easier to grow in such media.

The Guntur products located in the SE flank were divided into three geomorphology units, called as the crater, the body, and the foot of the volcano. The crater showed an opening feature on the top of the volcano. The body of the volcano is characterized by spreading structure. This unit is dominated by pyroclastic flow deposit. The foot of the volcano is located in the lowest slop, dominated by lava flow structure (Figure 3).

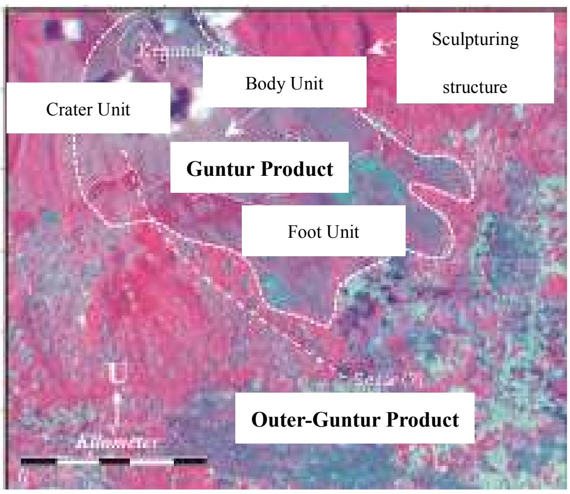

Figure 3. Geomorphology from ASTER image shows the differences of volcanic product distribution.

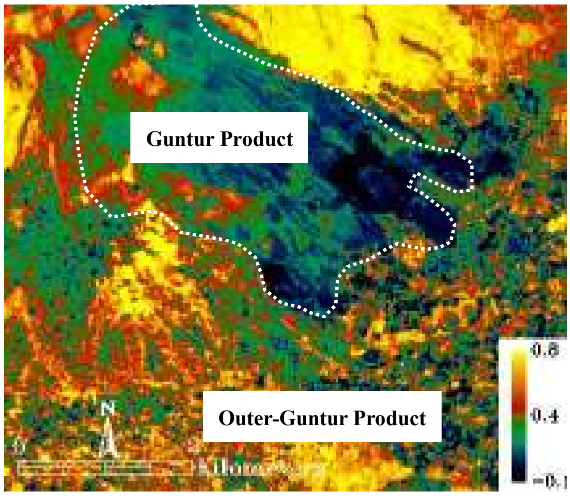

Figure 4. Low NDVI value of Guntur volcano represent as rare vegetation.

4. DIGITAL GEOLOGICAL MAP GENERATION

4.1. Lithological Unit Identification

The geological map was generated by using ASTER image processing validated by field observation and laboratory analysis. The good result was achieved because of lack of cloud and vegetation condition. Moreover the vegetation around the Guntur Volcano is rare and only grass and small vegetation growth in few parts (Figure 4). Such this condition makes possibility to divide lithological units more detail. Generally there are two volcanic products covered almost whole volcano; those are pyroclastics deposit and lava flows deposit. The pyroclastics deposit covers more than half part of the volcano. This product could be mapped by using supervised parallelepiped classification of ASTER images (Figure 5). The pyroclastic materials are common product ejected by explosive eruption.

There are two types of pyroclastic deposits found in the study site; those are pyroclastic flows and pyroclastic falls deposit. The differences between those volcanic products are usually found directly in the field observation activity. However in ASTER image (Figure 6) we could see the differences between pyroclastic falls (Pj) and flows (Pa) based on textures of the images. For ASTER images in layer stacks RGB for Band 3-2-1, the pyroclastic flows typically correspond to dark green color, smooth texture and flow structure. The green color represent as bare land and smooth texture originate from tephra. Bare land coincided with un-vegetated area, mining site, or man made. Flowing structure is caused by flowing process from this pyroclastics depositional process. The pyroclastic falls cover around the crater. On the ASTER image band 3-2-1 shows the flows structure diffusing from crater as a center part of the tephra. Based on field observation, this unit condition is un-vegetated or opened area, therefore the green color dominates on the images. The flow direction of this unit is toward to the lower topographic symmetrically.

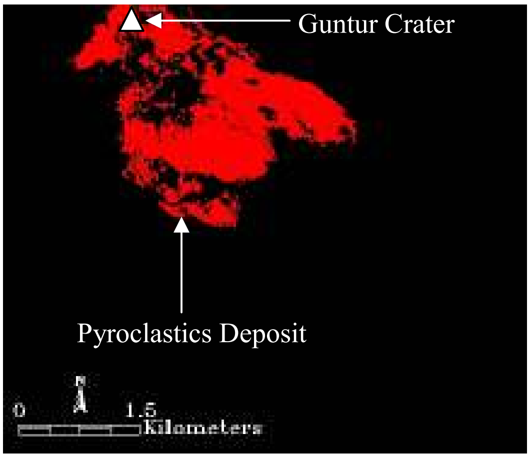

Figure 5. The pyroclastic deposits detected by Parallelepiped Supervised classification.

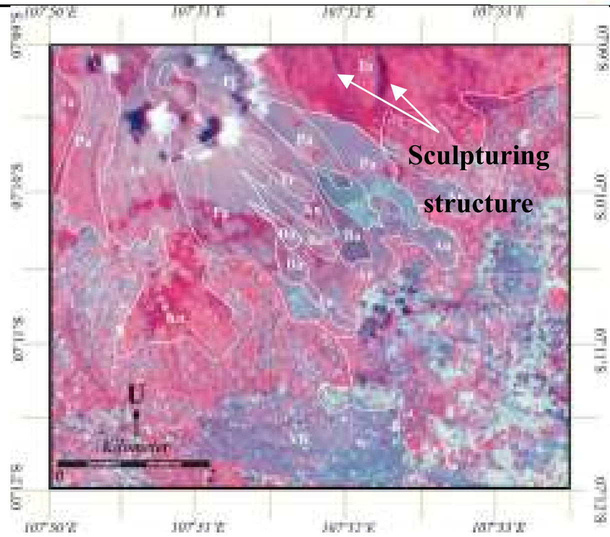

Figure 6. ASTER image classification validated by field observation

The second volcanic products detected are lava flow deposits which are divided into three rock types: Andesitics (An), Basaltics (Ba), and Trachiandesitics (Ta) rock. In the ASTER images band 3-2-1 for RGB, the Andesitics lava (An) corresponds to rough texture and green color mixed with red color (Figure 6). The red color was caused by radiance of grasses and green color consistent with bare land which is dominated by Andesitic rocks. In Guntur volcano, this lava is functioned as a reservoir fractured media of the hot spring around Cipanas, Tarogong. Consequently the minerals in the rock were altered generally.

The second lava unit is the Basaltic rocks (Ba). This unit has flowing texture, dark tone, high relief compared with surrounding color (Figure 6). The basaltic lava distribution in the field shows rough at the surface. At the some outcrops showed the lava tongue which implies the flow direction of the lava. Flowing texture on the image correlated with lava flow elongated to the SE direction. Dark tone on the image is caused by basaltic rocks which contain mafic minerals such as pyroxene, hornblende, and biotite.

The third lava unit is Trachiandesitic rocks (Ta). This unit is associated with Outer-Guntur product. This product covered by dense vegetation, showed as red color with sculpturing structure (Figure 6). This structure is typical caused by erosion. More erosion occurred implies the material exist in this area becoming older than other parts. Therefore Ta unit must be older than An and Ba unit. It was also proved by dating data that will be explained the discussion chapter.

4.2. Spectral Analysis of Altered Rocks

In addition to generate a geological map, we also tried to know the characteristics of altered rocks found in the field. The alteration rocks are an important key to know the geothermal system exist beneath the study site. Some laboratory experiments have been done using SolidSpec spectrometer for some rock samples. The result is shown in Figure 7.

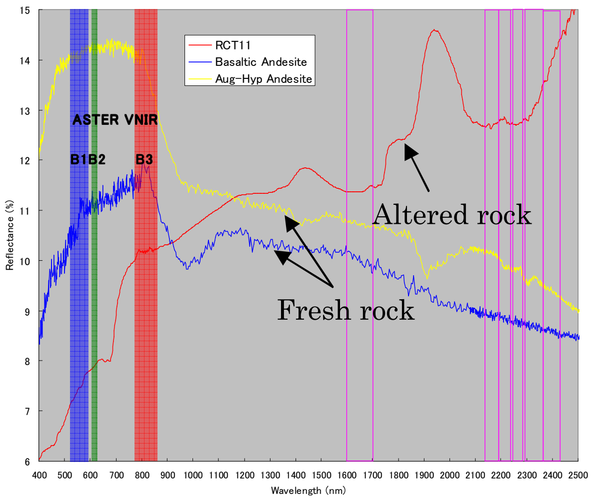

Figure 7. Spectral of the altered rock sample compared with fresh rock sample using SolidSpec.

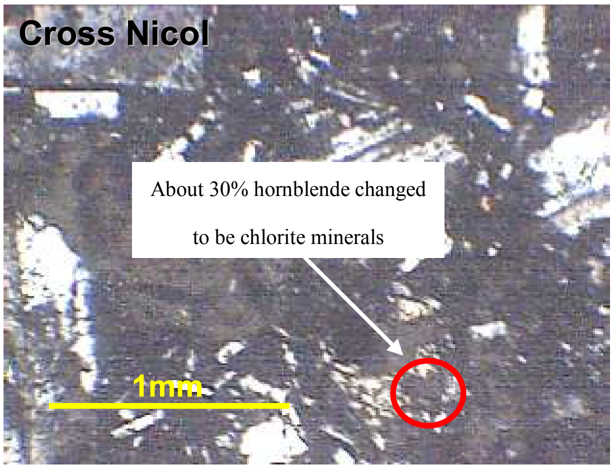

Figure 8. Micrograph of single thin section (crossed polarization) of altered rock sample shows alteration mineral.

The spectrometer used a wavelength ranged from 0.4-2.5 μm. The altered rock sample shows contrary different spectral behavior with the fresh rock. For the fresh rock the spectral increase relatively in 0.4-0.8 μm and decrease in 0.8-2.5 μm. Contrary with the fresh rock, the altered rock shows that the spectral increase in 0.4-2.5 μm. The fresh rock spectral sample is taken from Jet Propulsion Laboratory (JPL) plotted together with the altered rock sample from Guntur volcano. These spectral characteristics of the rocks are useful for ASTER image interpretation. The low spectra for the altered rock are located in band 3, band 2, and band 1 respectively. It implies low intensity of ASTER images probable consist of altered rocks. This is important consideration when interpreting the ASTER images. The altered rock distribution in ASTER images which is located in the low intensity is caused by the chlorite mineral. It was proved by petrography analysis (Figure 8). About 30% of hornblende minerals were altered to be chlorite. This mineral causes dark green color in the ASTER images. The green darker color was caused by radiance of the object is less than irradiance and caused low reflectance. It was showed by the result of spectral analysis of rock samples.

5. SUBSURFACE STRUCTURE OBSERVATION

In this study, tomography analysis was used to predict subsurface condition and evaluate the magma chamber location beneath Guntur Volcano. With tomography data we could see the depth of low velocity deviation of P and S wave, suggesting a high potential for heat source. The arrival times of Primary wave (P-wave) and Secondary wave (S-wave) have been used to investigate the internal structure of the Guntur Volcano. In the process of hypocenter determination, we employed a grid search method using a 1D-velocity layer. A three circles intersection method has been used to guide the grid search method. In the tomography process, the minimum travel time from a source to a receiver has been calculated by using 3D ray tracing with a pseudo bending method. Based on an irregular source and receiver distribution the block element has been chosen to be 2 x 2 x 2 km^3. The P and S wave tomograms (Figure 9-12) indicate that there are several negative anomalies under the Guntur Volcano associated with hot materials beneath the Kamojang Caldera, Gandapura Caldera, and Guntur Summit. This relation suggests that the associated volcano material tends to be more fluid like. Meanwhile, the negative anomalies in the P and S wave models also associate with a positive anomaly in the bulk sound velocity tomogram. This can be interpreted that the material tends to be more incompressible.

We assumed an interest depth beneath Guntur crater about 2-4 km under sea level, which have low velocity of P and S wave which possibly represent the heat source of geothermal system of Guntur Volcano (Nugraha, 2005). Figure 9-12 are tomography for P and S wave and its cross-section. Dots are hypocenter and percent scale is velocity perturbation relative to velocity of 1D first model, decrease in percent meant decrease in velocity assumed as weak zones.

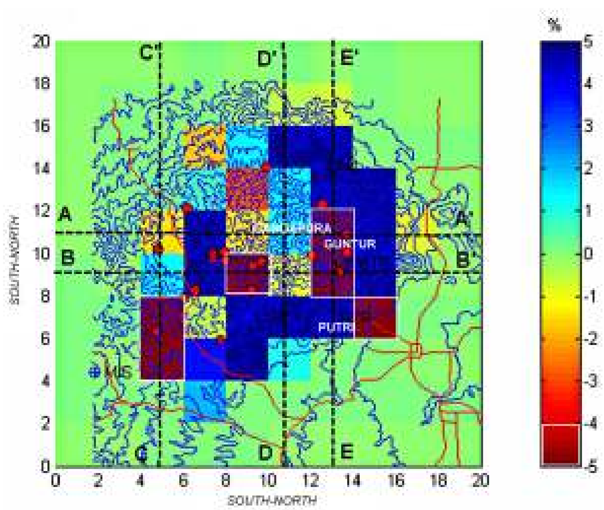

Figure 9. Slicing of P wave velocity in depth 2-4 km

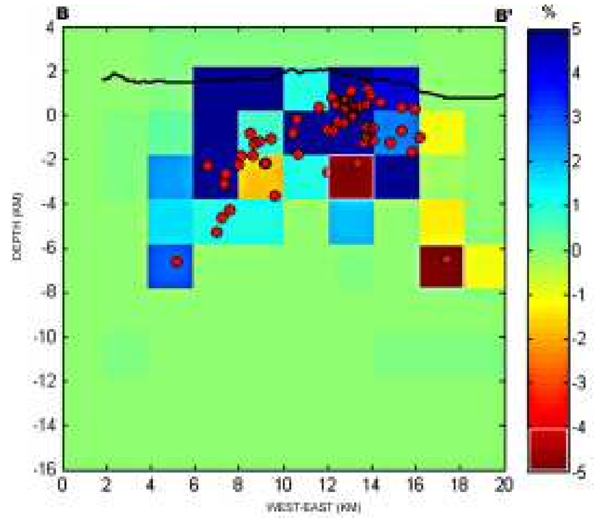

Figure 10. Vp Tomography (BB' Cross Section) past over Guntur volcano

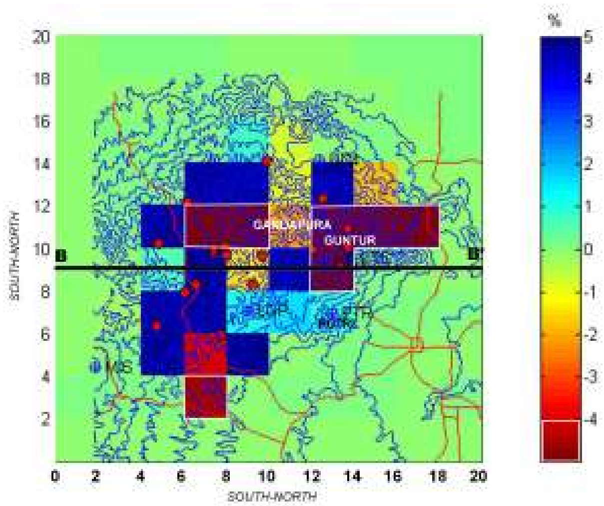

Figure 11. Slicing of S wave velocity in depth 2-4 km

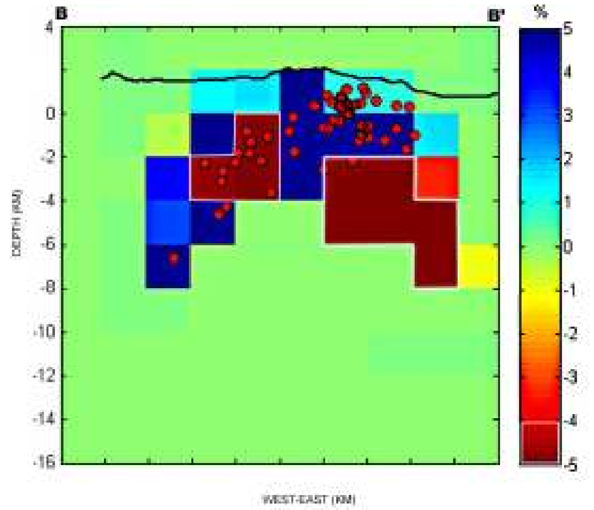

Figure 12. Vs Tomography (BB' Cross Section) past over Guntur volcano

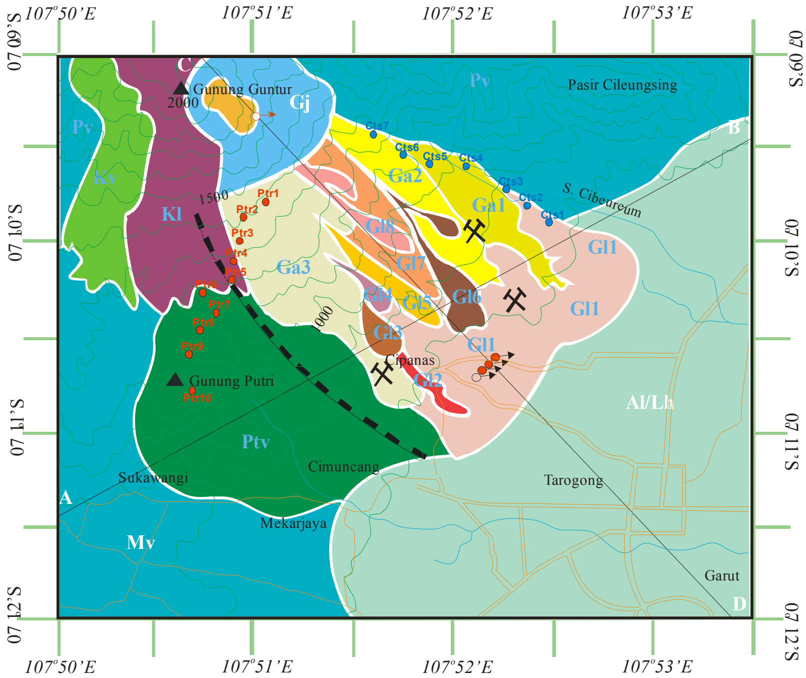

Figure 13. Geological map and its structure based on ASTER image interpretation validated by field observation and laboratory analyses.

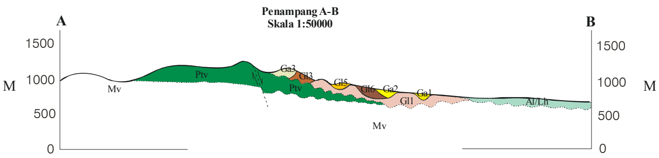

Figure 14. A-B Geological cross-section.

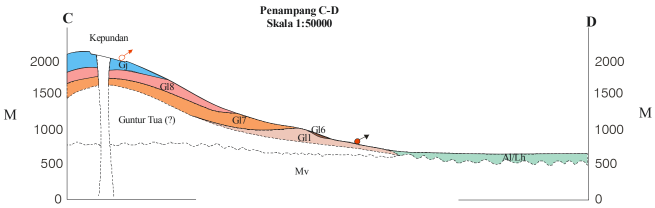

Figure 15. C-D Geological cross-section.

6. RESULT AND DISCUSSION

Generating a geological map traditionally usually spends a lot time and financial. It was of course depending on coverage area and condition. In volcanic area, high topography, dense vegetation without a good route to be reached, makes geologist facing problem to map the area. However, the ASTER image interpretation makes work in such area is easier, as shown in Figure 13 after validated with field observation and laboratory analyses. By this we did not need to check whole areas to make this geological map. We only make sampling at some interesting points controlled by the coordinate location.

Analysis for ASTER band 3-2-1 is useful to distinguish morphology and lithological units. Morphology of Guntur volcano is different with other products surrounding the volcano. The Guntur product is characterized by flow impression and distinguished by Outer-Guntur product that shows sculpture impression. Each lithology corresponds to a certain feature on the ASTER image. The feature represents as volcanic product deposits such as lahars, lava, and pyroclastics.

Table 1. Some Keys of Image Interpretation Using ASTER Layer Stack R: Band 3, G: Band 2, B: Band 1

No	Materials	Characteristics
1	Andesitic rocks (lava)	Rough texture, greens dark color mixed with red color.
2	Basaltic rocks (lava)	Flow texture, dark tone, high relief, elongated toward from the eruption center.
3	Dense vegetation	Red color.
4	Fault lineament	High contrast elongated toward to one direction
5	Man made (road, building, etc.)	Green color, rough texture, and polygonal structure typical for building.
6	Mining, landslide, bare soil	Light green-light blue.
7	Old lava deposits	Red color (covered by dense vegetation), sculpture structure caused by long erosion.
8	Pyroclastic Falls	Flowing structure, cycled, symetrics.
9	Pyroclastic Flows	Green color (uncovered area), smooth texture, flow structure.
10	Water	Dark
11	Wet Vegetation (paddy field)	Green dark color mixed with red dots color

Finally, we succeed to divide 18 lithological units detail. Each unit corresponds to lithological type and its stratigraphic position. Guntur product was named with G capital in the front of text unit. For example, Gl1 means Guntur lava 1. This unit is older than Guntur Lava 2 (Gl2). The clearer differences between two successions are shown by geological cross-sections in Figure 14 and Figure 15, respectively. On the other hand, geological structure was detected. This structure is a normal fault and revealed from the ATSER image as a bright contrast and validated by field observation. The normal fault is indicated by black arc line with fault symbol (Figure 13).

In addition to volcanic product succession, we also adopted a reference of rock dating data for two oldest volcanic products, Ptv and Mv. Ptv is the oldest product with age 0.14 M year ago. The following product is Mv with age 0.08 M year ago (Purbawinata, 1990). Other products after Mv must be younger than 0.08 M year. From the Guntur lava 7 (Gl7) to the pyroclastic deposits are the youngest volcanic products. These products are the results of the latest eruption of Guntur volcano in 1840 to 1847. However, for Al/Lh unit is different with others. The material of this unit is a mixture material. This unit is resulted from sedimentation of other materials, located in the valley and slope of the volcano. To make clearer result and also for reference when interpreting the ASTER images, we proposed a chart of characteristic of ASTER images for Band 3-2-1 in Table 1. The analysis will be valid after applied atmospheric correction of the ASTER images and if the coverage area of vegetation is rare.

In addition to relation between surface and subsurface condition, we found that some parts of lava flows deposit were already altered caused by geothermal system beneath the volcano. The alteration rocks were detected using spectral analysis because the spectral of altered rock is slightly different with the fresh rock. The altered rock deposits are located in dark portion of ASTER Band 3-2-1 images. The dark portion is caused by emission of alteration minerals, which is shown in the thin section image of petrography analysis. On the other hand, the tomography seismic detected the low velocity zone supposed to be the magma chamber located in depth about 2-4 km under sea level. The tomography analysis stated that the geothermal system exists beneath Guntur volcano. The heat from geothermal system can change the fresh rocks at the upper part to be altered rocks. However, Guntur volcano is a young volcano, the component of geothermal system supposed to have not yet developed completely. Lack of the cap rock caused the hydrothermal leaked to the surface. Therefore, efficiency for exploration is quiet low. Ideal alternative is used for tourism due to good nature and many hot springs found in the foot of the volcano.

REFERENCES

[1] Abrams, M., Hook, S., 1998. ASTER User Handbook Version 2, Jet Propulsion Laboratory, California Institute of Technology, California.

[2] Ninomiya Y., Fu B., Cudahy T. J., 2005. Detecting Lithology with Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Multispectral Thermal Infrared "Radiance-at-Sensor" Data, *Remote Sensing of Environment*, 99, 127 – 139.

[3] Nugraha A., 2005. Studi Tomografi 3-D Non Linier untuk Gunung Guntur dengan Menggunakan Data Waktu Tiba Gelombang P dan S. thesis of master program in ITB.

[4] Purbawinata, M. A., 1990. Petrology and Geochemistry of the Guntur-Gandapura Volcanic Complex, West Java, Indonesia", Ph.D Thesis, Univ. of Otago, Dunedin, New Zealand.

[5] Suwijanto, 2004. Aplikasi Remot Sensing Untuk Eksplorasi Mineral dan Hidrokarbon, A Short Course Material, LIPI, Bandung, 2004.