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Evolution of Rajabasa Volcano in Kalianda Area and Its Vicinity, South Lampung Regency

Evolusi Gunung Api Rajabasa di daerah Kalianda dan Sekitarnya, Kabupaten Lampung Selatan

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Abstract

Rajabasa Volcano (± 1281 m) and Lampung Tuff, located in the South Lampung Regency, is the main point in order to understand the evolution of Quaternary volcanism in the area. A remote sensing analysis and field geologic work are the methods of the study. The volcanism began with the construction period of the Pre-Rajabasa composite cone which was followed by the destruction period of the cone to form the Pre-Rajabasa Caldera having ca. 25 km in diameter. The present Rajabasa Volcano, along with cones of flank eruptions and monogenesis, has appeared in the Pre-Rajabasa Caldera depression. Those volcanic activities are considered as the second construction period. During the first and the second construction periods, basaltic to andesitic lava flows, pyroclastic breccias, and tuffs were erupted. The Rajabasa eruption points moved in WNW - ESE direction, which were possibly controlled by a subsurface weak zone. The Pre-Rajabasa Caldera erupted voluminous Lampung Tuffs having rhyolite in composition, and they are considered as a combination of pyroclastic falls, flows, and surges, or pyroclastic density currents.

Keywords: evolution, Rajabasa, volcano, Kalianda, Lampung, caldera

Sari

Keberadaan kerucut komposit Gunung Api Rajabasa (± 1281 m) dan Tuf Lampung di Kabupaten Lampung Selatan menjadi hal utama untuk mengetahui evolusi gunung api Kuarter di daerah tersebut. Metode penelitiannya adalah dengan melakukan analisis inderaja dan penyelidikan geologi di lapangan. Vulkanisme dimulai dengan pembangunan kerucut komposit Gunung Api Pra-Rajabasa yang kemudian diikuti oleh tahap penghancuran kerucut gunung api itu, sehingga terbentuk Kaldera Pra-Rajabasa dengan diameter ± 25 km. Gunung Api Rajabasa saat ini, bersama dengan erupsi lereng dan gunung api monogenesis, muncul di dalam cekungan Kaldera Pra-Rajabasa sebagai tahap pembangunan kedua kerucut komposit. Bahan penyusun Gunung Api Pra-Rajabasa maupun Gunung Api Rajabasa terdiri atas aliran lava, breksi gunung api, dan tuf berkomposisi basal sampai andesit. Gunung Api Rajabasa mempunyai titik letusan berpindah-pindah pada arah barat barat laut - timur tenggara, yang diduga dikontrol oleh zona lemah bawah permukaan. Letusan besar pembentukan Kaldera Pra-Rajabasa menghasilkan Tuf Lampung berkomposisi riolit yang berupa bahan piroklastika aliran, jatuhan, dan seruakan yang juga dikenal sebagai piroklastika arus pekat.

Kata kunci: *evolusi, Rajabasa, gunung api, Kalianda, Lampung, kaldera*

Introduction

In the south-southeastern tip of Sumatra Island, included into the South Lampung Regency, Lampung Province, the Rajabasa Volcano appears. The area studied is occupied by the Quaternary Rajabasa Volcanics (Qhv), Plio-Pleistocene Lampung Formation (QTl), and Andesite Unit (Tpv) as the result of Tertiary volcanic activities (Andi Mangga *et al*., 1994). So far, the relationship of the three volcanic activities is not clear. The eruption source of the Lampung Formation which has widely spread

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till the northern and northwestern parts of Bandar Lampung City, the capital of Lampung Province, has not been known yet. In general, the widespread (and thick) dacitic - rhyolitic tuff is the product of a very voluminous eruption like the Toba Tuff. The tuff is pyroclastic rock formed by fall and surge mechanisms. They cannot easily be separated, so they are overall called pyroclastic density currents (Druitt, 1998; Branney and Kokelaar, 2002). At the time of the eruption, part of composite cone of the volcano was destructed or disappeared, so it formed, a depression which has diameter of more than 2 km and it is called volcanic caldera. In the next period, a new volcano appeared in the caldera, like Anak Krakatau Volcano inside the Krakatau Caldera which was formed at the voluminous eruption in 1883, Bromo Volcano in Tengger Caldera, Batur Volcano in Batur Caldera, and Barujari Volcano in Rinjani Caldera.

This paper aims to investigate whether in the area of Rajabasa Volcano there is Pre-Rajabasa Caldera and Pre-Rajabasa composite Volcano which was active before the Rajabasa Volcano was formed. In order to achieve the purpose, a remote sensing analysis and a volcano-stratigraphic study in the field were used. Near the tuff source, the product of caldera eruption will be mixed with older rock fragments called co-ignimbrite breccia (Cas and Wright, 1987; Bronto, 2010). A composite volcanic cone was characterized by its content as basaltic-andesitic lava flow and volcanic breccia (Bronto, 2006).

The studied area is located at Rajabasa Volcano and its vicinity, South Lampung Regency with Kalianda as its capital (Figure 1). The studied area lies at coordinate of 105^0 33’ - 50’E and 5^0 40’ S - 55’ S.

Geological Setting

Geomorphology

The South Lampung Regency region consists of Rajabasa volcanic cone, hills, and plain. The Rajabasa Volcanic Cone (+ 1281 m) is an active volcano of B type (van Padang, 1951; Simkin and Siebert, 1994) characterized by the presence of solfatara field including fumarole, hot spring, mofette, and other geothermal features. The volcano occupies almost one third of the studied area. The

Figure 1. Locality map of the studied area in the Rajabasa Volcano, Kalianda, South Lampung Regency (in a small box).

hot spring is situated at the west and northwest foot of Rajabasa Volcano that is in Way Belerang and near Kalianda quay. The hilly area is located at the western part of Rajabasa Volcano and around Bakauheni harbour with various heights between 50 - 500 m asl. Most of the landscapes in Bakauheni area comprise hills with steep slopes consisting of Pliocene volcanics (Andi Mangga *et al*., 1994). The plain area (0 - < 50 m asl.) situated in the northern and eastern parts and occupying the widest part of the studied area mainly consists of Lampung Tuff (van Bemmelen, 1949) or Lampung Formation (Andi Mangga *et al*., 1994) and alluvial deposits.

Stratigraphic Setting

Based on the geological map of Tanjungkarang Quadrangle (Andi Mangga *et al*., 1994), there are three units of volcanic rocks in the studied area, varying from Tertiary to Quaternary in age; those are Andesite Unit, Lampung Formation, and Rajabasa Volcanic Rocks (Table 1). The Andesite Unit is composed of andesitic lava as the product of Tertiary volcanism spreading out in the western to the southeastern parts of Rajabasa Volcano. Based on the lava flow characteristics occurring on the current active volcano, this Andesite Unit are predicted to be developed not far from the eruption source. The

Table 1. Stratigraphy of Volcanic Rocks in the Rajabasa Volcano and Its Vicinity, South Lampung Regency (modified from Andi Mangga *et al*., 1994)

Age	Rock Unit Name	Description
Quaternary	Rajabasa Volcanic Rocks (Qhv)	Lava (andesite-basalt), breccias, tuff, spread out locally in the Rajabasa Volcano, southern part of Kalianda City.
Quaternary-Tertiary	Lampung Formation (QTI). Previous name Lampung Tuff (van Bemmelen, 1949)	Pumiceous tuff, rhyolitic tuff, tuffite, welded tuff, tuffaceous claystone, tuffaceous sandstone, distributed widely from Bakauheni to northern Kalianda till northern part of Bandar Lampung City. Pumiceous tuff, yellowish grey-greyish white, medium- to coarse-grained, poorly sorted, mainly comprising pumice and rock fragments. Rhyolitic tuff, brownish white, slightly jointed, hard. Tuffaceous sandstone, yellowish broken white, subrounded, partly pumiceous, somewhat soft, often shows cross bed structure, generally of dacitic composition.
Tertiary	Andesite (Tpv)	Andesitic lava, light-dark grey, hard, porphyritic; plagioclase, amphibole, and pyroxene phenocrysts embedded in aphanitic groundmass; outcrop relatively fresh, strongly/sheeting jointed; cropping out in the eastern part of Rajabasa Volcano; unconformably overlain by the Lampung Formation.

Lampung Formation, which is also known as the Lampung Tuff (van Bemmelen, 1949) is rhyolitic tuff rich in pumice, and it crops out vastly and thickly (200 m). Typicaly, the tuff is a product of volcanic caldera eruption like Toba and Krakatau Tuffs.

The Rajabasa Volcanic Rocks are included into young volcanic deposits (Quaternary) as the products of Rajabasa volcanic eruption. The rocks comprise basaltic-andesitic lava, breccias, and tuff forming the Rajabasa volcanic cone body. The rock composition tends to indicate that the Rajabasa Volcano is a composite or strato cone type.

Geological Structure

The geologic map of Tanjungkarang Quadrangle (Andi Mangga *et al.,* 1993) shows that the pattern of fault and lineament structures has NW - SE and N - S directions. The structural pattern having NW - SE direction is believed as the extension of Sumatran Fault pattern (Katili, 1975) occupying exactly the SSE edge of Sumatra Island. The fault pattern having N-S direction is estimated to be related with the pattern of basement structure commonly found in the Java Sea (Martodjojo, 2003). The structural pattern of the basement rock may be as the cause of the rise of volcanism behind the volcanic arc forming a linear eruption of Sukadana Basalt (Soeria-Atmadja *et al*., 1986) in East Lampung area.

Results

Remote Sensing Analysis

Based on the remote sensing analysis, it is known that in the eastern part of Rajabasa Volcano there is an oblique line feature bordering the foot of Rajabasa Volcano and other landscapes in the eastern part (Figure 2). Series of hills and river channels at the eastern part have a semi-radial pattern with NE to E direction further away from the Rajabasa Volcano. The satellite image can be compared with the feature of Ijen Caldera in East Java. The oblique line of Ijen Caldera rim occurs only at the northern part as a border between Ijen Caldera margin at the southern part and the remains of the Ijen composite volcano cone body at the northern part. The hill ridge and river flow at the northern part of curve line of the Ijen Caldera ridge or at the remains of Ijen composite volcanic cone body show a radial pattern in NW, N, and E directions, farther away from the

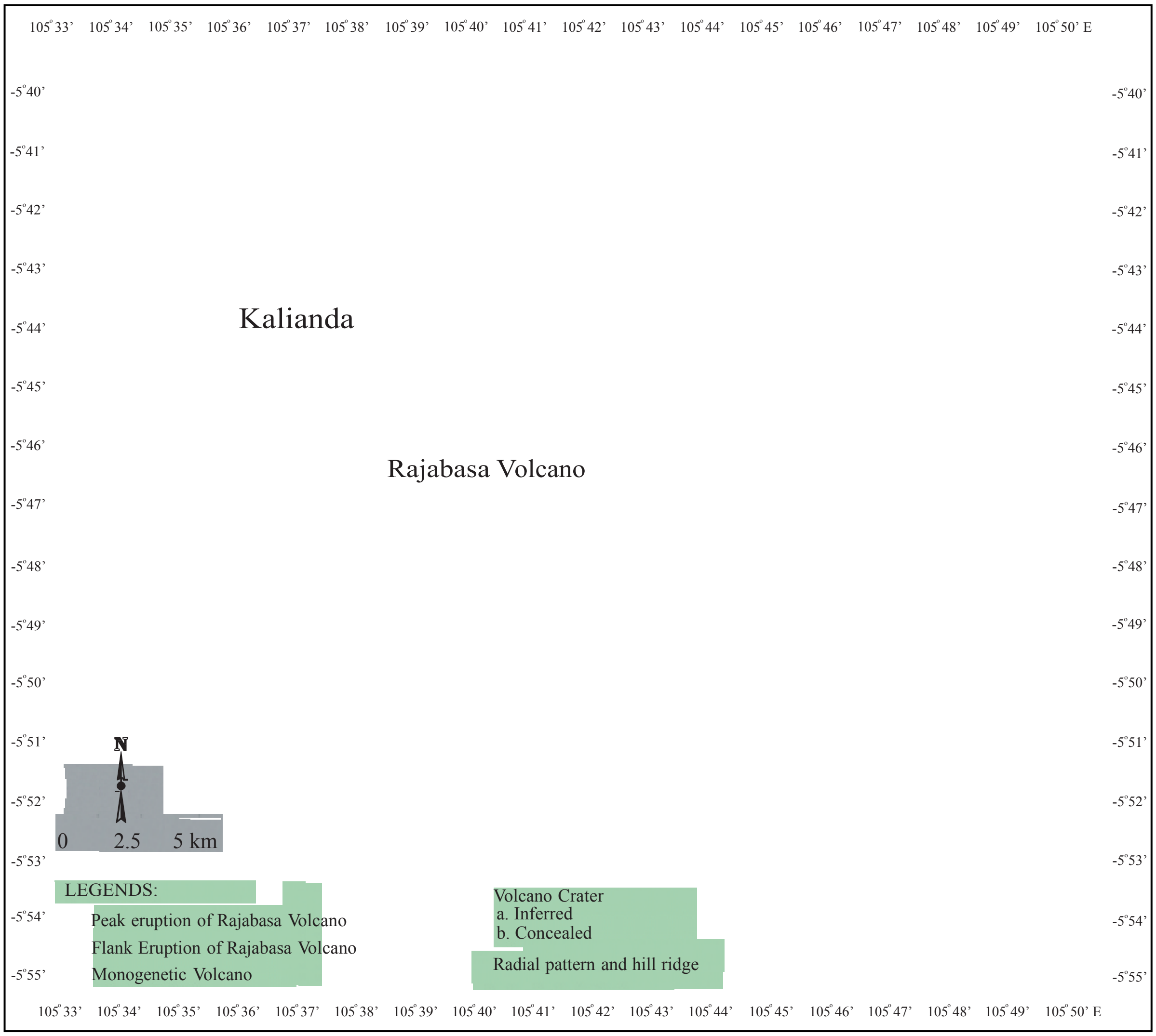

Figure 2. Satellite image analysis of the Rajabasa Volcano and its vicinity, South Lampung Regency. The arrow shows the spread direction of the hill ridge and river drainage pattern farther away from the circle of caldera ridge.

centre of Ijen volcanic eruption. Therefore, the curve line at the eastern part of Rajabasa Volcano can be estimated as the ridge of Pre-Rajabasa Caldera and the landscape at the eastern part as the remains of Pre-Rajabasa composite volcanic body. However, the Pre-Rajabasa Caldera scarp is not found due to be buried by the Rajabasa Volcanic eruption material, both as primary material and debris.

Series of hills and river channels farther away from the Rajabasa Volcano having a ENE subradial pattern can still be observed on the AMS topographic map issued by Jawatan TNI AD (Indonesian Army Service) (1974) (Figure 3). The landscape having radial pattern with ENE begins from a high between Cugur ridge to the north till the east of Karangsari Village.

The Rajabasa Volcano is not a single volcanic composite cone, but it consists of some composite cones (Figure 2). At the peak eruption, the centre of eruption moved from SE to NW of which each developed its own volcanic cone. Volcanic activities also occurred at the flanks and foot as a phenomenon of monogenetic volcanism. Hence, all the Rajabasa volcanic cones with flank and foot eruption points are still in the complex estimated as the Pre-Rajabasa Caldera.

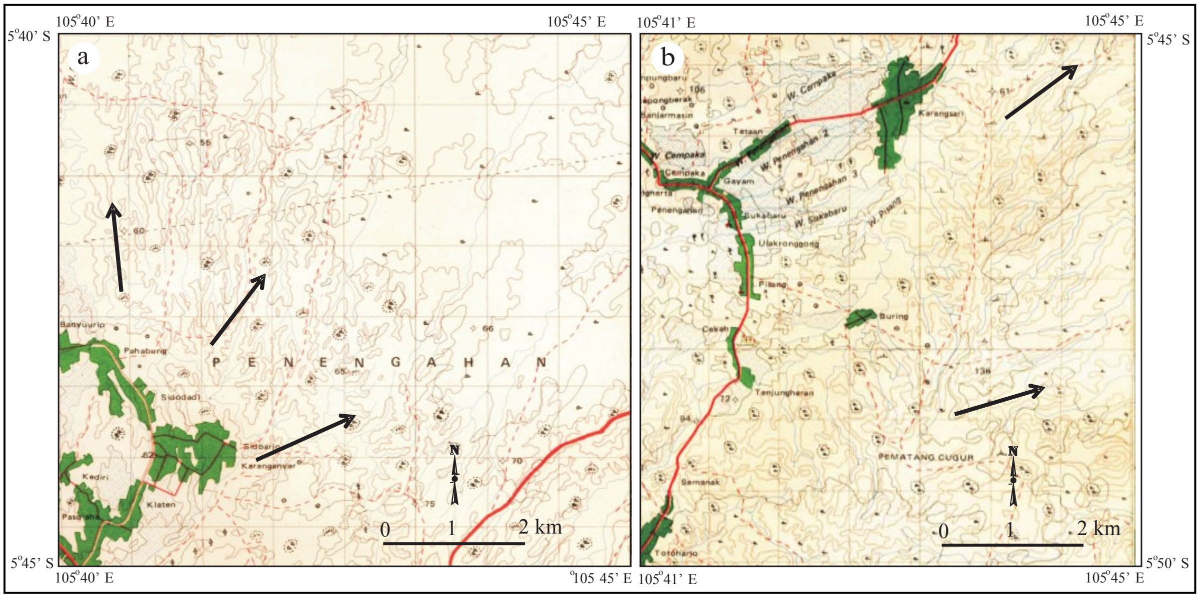

Figure 3. AMS topographic map of the Penengahan Sheet in the northeastern (a) and eastern (b) parts of Rajabasa Volcano showing river drainage pattern and contour line farther away the Rajabasa Volcano (arrow direction). In Figure b, the drainage pattern begins from the east of Karangsari Village towards south till Cugur Ridge.

Field Data of Pre-Rajabasa Volcano

On the basis of investigation in the northern part of Rajabasa Volcano that is in the southern of Lubukjukung Subvillage, Negeri Pandan Village, Kalianda Sub-Regency (location 1, Figure 4; coordinate 5^0 40’ 31.2” S & 105^0 38’ 56.1” E), an oblique landscape feature trending south or facing the Rajabasa Volcano was found consisting of andesitic lava boulders. Meanwhile, a landscape in the northern part is dipping to the north. Thus, this location precisely lies on the curvilinear line as shown on the satellite image of Figure 2 and AMS topographic map (Figure 3). Towards the west side from the location on the topographic map there is a hill peak named Sesatan Heni Mountain (T.150/29ft.) and on the side of Kalianda - Merakbelatung road the hill is named Capa Mountain (T.1510/28ft.). In the eastern part of the Capa Mountain near the sport stadium of South Lampung (location 2, coordinate 5^0 41’ 48.9” S & 105^0 35’ 30.8” E) an oblique morphology facing Rajabasa Volcano and comprising andesite boulders can still be seen. Therefore, the landscape from location 1 in Lubukjukung Subvillage to the west towards Sesatan Heni and Capa Mountains is suggested to have been the northern part of caldera ridge of Pre-Rajabasa Volcano.

The topographic change of Rajabasa Volcano foot with the pattern of hill ridge and river channel radiating to the N - NE can easily be observed in the AMS topographic map (Figure 4). In location 3, at the eastern part of Sukaraja Village (Kuripan Subvillage 3, coordinate 5^0 42’ 29.6” S & 105^0 41’ 05.0” E) a contact between the Lampung Tuff and older rocks below was found, although it has been weathered and oxidized (Figure 5). About 300 m to the west, the Lampung Tuff overlies andesitic boulders. Further to the southeast, at the slope of Pisang Stream (location 4, coordinate 5^0 43’ 04.8” S & 105^0 41’ 21.2” E) the Lampung Tuff overlying weathered breccia was recognized. The data prove that the Lampung Tuff overlies older rocks consisting of andesite, and they are suggested as part of the Pre-Rajabasa composite Volcano.

Figure 3b shows that the drainage pattern of the rivers are radial flowing to E - NE in the eastern part of Karangsari Village towards the south till Cugur Ridge is clearly separated by Way Pisang channel, whilst in the western part by a ridge of Karangsari - Cugur High. This supports the presence of a curvilinear line on the satellite image (Figure 2). From the investigation on the SE foot of Rajabasa Volcano, the landscape of Mount Tangkil which lies

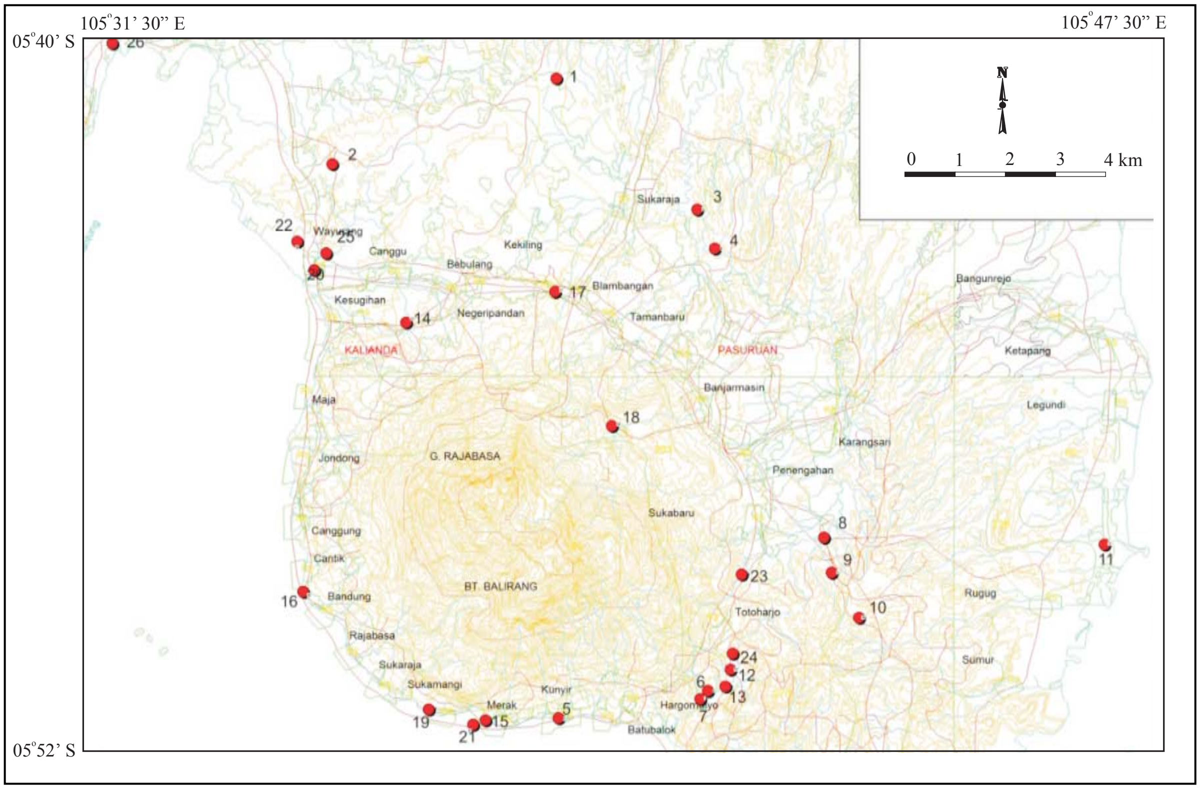

Figure 4. Locality map of observation sites with an AMS topographic basemap showing series of hills and river channels having a subradial drainage pattern to the N-NE in the NE part of Rajabasa Volcano. The basemap is modified from AMS topographic map of scale 1:50.000; Jantop TNI AD 1974, Sheet 2314-III (Kalianda) and Sheet 2313-III (Penengahan).

Figure 5. A contact between older volcanic rock (A) and Lampung Tuff (B) in location 3, Kuripan Subvillage 3, coordinate 5^0 42’ 29.6” S & 105^0 41’ 05.0 E.

on the SW part of Cugur Ridge is seen to develop an oblique sloping hog back. Meanwhile, the morphology of the lava flow of the Rajabasa Volcano occupies an area between Mount Tangkil and the peak of Rajabasa Volcano. Thus, the high ridge in the eastern part of Karangsari Village towards Cugur Ridge and Mount Tangkil can be decided to have been the eastern part of the Pre-Rajabasa caldera ridge. Suswati *et al.* (2001) includes the Pre-Rajabasa Volcanic rocks into the unit of Tangkil Old Volcanic Product (Tv).

A very good outcrop of the Pre-Rajabasa volcanics overlain by the Lampung Tuff occurs in Way Andeng, location 6 (coordinate 5^0 49’ 49.1” S

& 105^0 41' 15.5" E; Figure 6a & b). Further to the downstream, at location 7 (coordinate 5^0 49' 54.2" S & 105^0 41' 07.8" E; Figure 6c & d), in Pancuran Village near PDAM (local government drinking water company) dam, the Way Andeng forms a very deep and narrow valley cutting andesite lava interfingering with breccia as a characteristic of a composite volcano. The andesitic lava has a grey colour, undergone segregation impressing layering, and sheeting and columnar joints. The segregation was caused by mafic mineral interfingering with felsic mineral assemblages. The grey mafic mineral layer has sometimes been oxidized to become brick red in colour.

In the eastern part of Rajabasa Volcano by the Trans Sumatra road (location 8, the south of Buring Village), the Pre-Rajabasa volcanic rock crops out very well due to exploitation. The rock is porphyritic andesitic lava, sheeting jointed, porphyroaphanitic - glassy texture, with fine-grained plagioclase and pyroxene phenocrysts. Considering the AMS topographic map (Figure 3 and 4), the andesitic lava in this location 8 occupies the west scarp foot of Karangsari - Cugur High ridge. It means that the andesite lava is part of the body of Pre-Rajabasa composite volcano. A bit further to the southeast part, still by the Trans Sumatra road, in front of Bakauheni Sub-Regency office (location 9), the Pre-Rajabasa volcanics are overlain by the Lampung Tuff. Thus, the landscape beginning from Mount Tangkil hogback, facing the Rajabasa Volcano trending to the north (Cugur Ridge scarp), continuing to the northwest in location 4 and 3 can be related to the presumed northern caldera ridge from Lubukjukung Subvillage (location 1) to Sesatan Heni and Capa Mountains as the caldera ridge of the Pre-Rajabasa Volcano. Volcanic rocks such as andesitic lavas and boulders as well as their weathered material underlying the Lampung Tuff are the eruption product of the Pre-Rajabasa composite Volcano.

Figure 6. a & b: A contact between the Pre-Rajabasa volcanic rock (1) and Lampung Tuff (2) in location 6, Way Andeng, above drinking water dam (PDAM), at the SW foot of Mount Tangkil, coordinate 5^0 49' 49.1" S &105^0 41' 15.5" E. c & d: Lava and volcanic breccia outcrop composed of andesite, products of Pre-Rajabasa volcanic activities, location 7 downstream of Way Andeng, beneath (PDAM), coordinate 5^0 49' 54.2" S & 105^0 41' 07.8" E.

Lampung Tuff

The Lampung Tuff (van Bemmelen, 1949) or Lampung Formation (Andi Mangga *et al*., 1994) is widely distributed, beginning from the east to the northwest of Rajabasa Volcano. In the southeast, the Lampung Tuff only occupies the sloping morphology among hills consisting of older volcanic rocks.

The Lampung Tuff is very unique because typically the colour is white and in many exploiting places it crops out thickly (Figure 7) with volcanic ash as the main material (sand-clay grains) and lapilli pumice (diameter of 2 - 5 cm). The addition material is andesite lithic fragment - basaltic andesite predicted to be derived from the Pre-Rajabasa volcanics, broken into pieces and thrown away (Figure 7b). Spheroidal weathering structure within relatively fresh rhyolite boulders is found in location 9 and 10 (Figure 7c & d). The weathered boulders are embedded within pumiceous tuff rich in accretionary lapilli. In this location, igneous rock fragments in granitic texture were also found. Besides the tuff is massive and thick, in many places various layer structures from thick (30 - 50 cm) to thin (a few cm) and mega cross bedding structure were also found in a big or small scale.

Descriptive data show that the mechanism of Lampung Tuff formation is dominated by pyroclastic flow along with surges known as non-welded ignimbrite or pyroclastic density currents (Branney and Kokelaar, 2002). The abundance of accretionary lapilli in the Lampung Tuff (Figure 8a) shows that the rock was deposited in a humid terrestrial environment. It is also supported by the presence of silicified burnt wood trunk fossils,

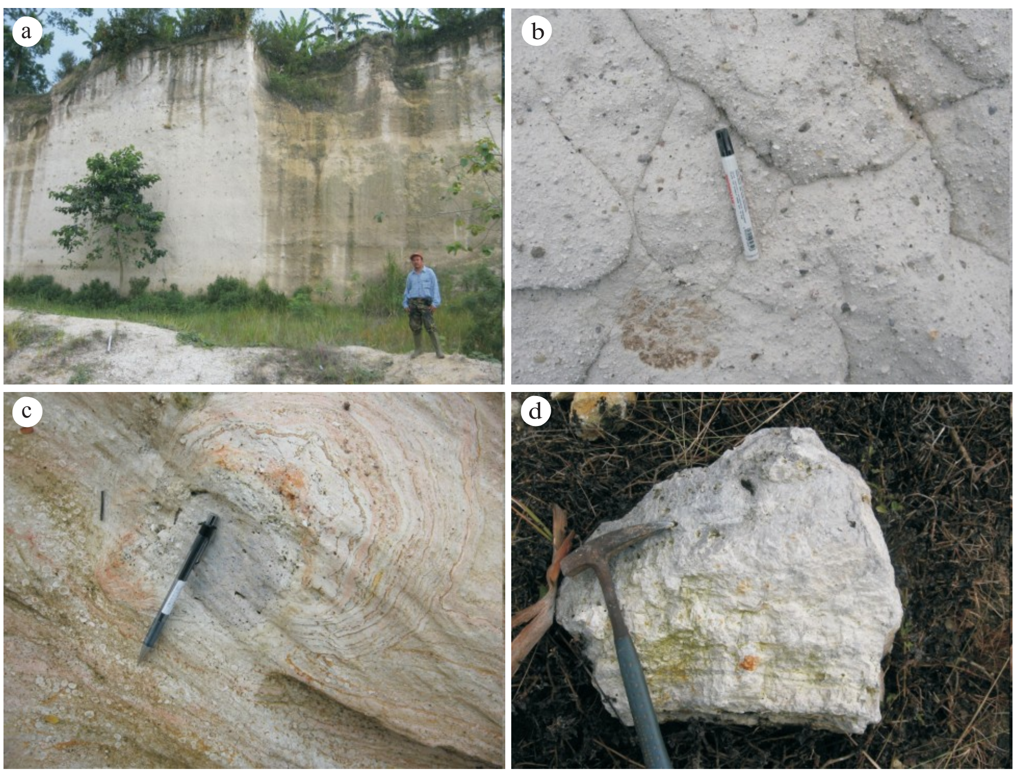

Figure 7. Some appearances of the Lampung Tuff outcrop; a. By the eastern part of Trans Sumatra road of Bakauheni - Kalianda, Hatta Village, Bakauheni Sub-Regency, location 10, coordinate 5^0 48' 38.9" S & 105^0 43' 33.6" T; b. By the western part of the Eastern Cross road, Trigama Village, Panengahan Sub-Regency, location 11, coordinate 5^0 47' 32.6" S & 105^0 47' 18.5" E. A dark rock fragment consisting of basaltic andesite is suggested to be derived from old rocks spread out along with the eruption; c. A rhyolite boulder embedded within the Lampung Tuff in Way Andeng, location 12, coordinate 5^0 49' 26.1 S & 105^0 41' 36.1 E. The Lampung Tuff is composed of plenty rounded accretionary lapilli, on left-lower part of the figure; d. A rhyolite boulder from the Lampung Tuff, at location 10, coordinate 5^0 48' 38.9" S & 105^0 43' 33.6" E.

having not less than 1 m in diameter (Figure 8b - c), buried in direction of N 145^0 E. Moreover, in the surrounding area smaller wood twigs can still be found. The falling direction and the buried woods show that the pyroclastic flow came from northwest (Pre-Rajabasa Caldera). The outer part of the woods has been mixed with brown oxidized volcanic ash (Figure 8d). In some places, the wood fossils had totally been oxidized so they influenced the colour of the tuff around them to become brown in colour.

In location 13, polymict breccia recognized comprises very angular basaltic andesite boulders of 25 - 40 cm in size, compact to scoriaceous, and dark grey to brick red and oxidized brown, embedded within the Lampung Tuff (Figure 9). The presence of angular size tends to indicate that the rock fragments were originated from older volcanic rocks that had been broken up and thrown away along with lapilli ash of rhyolitic pumice during the eruption of Pre-Rajabasa Caldera construction. Thus, the polymictic breccia can be assured as co-ignimbrite breccia formed together with the Lampung Tuff deposited nearby the source. It is evidenced by the co-ignimbrite breccia occurrence (location 13) which is still in the Pre-Rajabasa caldera ridge circle.

Rajabasa Volcano

Both from the appearance on AMS topographic map, satellite image (Figure 2), and the landscape in the field, it is known that the Rajabasa Volcano consists of some composite cones. This was caused by the crater or eruption point movement at SE-NW direction. Old craters at the volcano peak, lying at the centre and SE areas have a horseshoe shape facing WNW a new volcanic cone in the front. The highest peak at the northwesternmost part having a circular shape with diameter of 300 m, is still at the horseshoe crater facing NW. The crater is suggested to be the youngest eruption point in Rajabasa Volcanic Complex. Further to the NW, at Rajabasa

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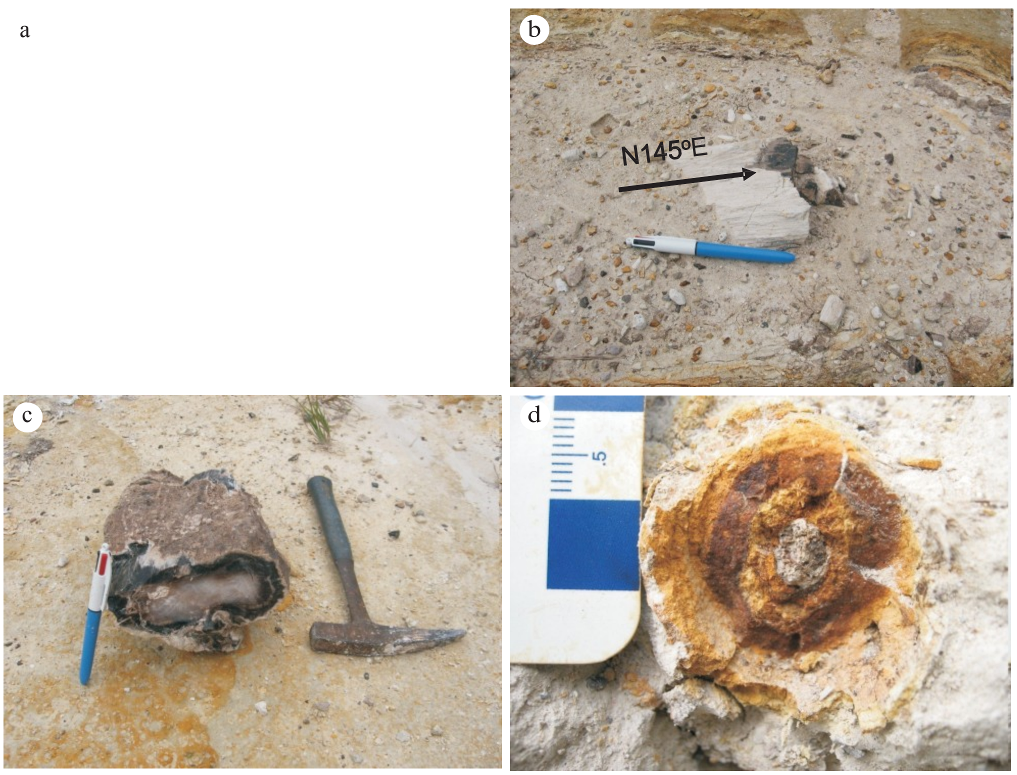

Figure 8. Outcrop appearances of accretionary lapilli and wood fossil within the Lampung Tuff, location 11, coordinate 5^0 47’ 32.6” S & 105^0 47’ 18.5” E, by the western part of Eastern Cross road, Trigama Village, Ketapang Sub-Regency; a. Accretionary lapilli; b. A wood fossil embedded within the Lampung Tuff; c. A silicified wood fossil (b) having been collected; d. A brown oxidized wood fossil.

Figure 9. Some outcrop appearances of co-ignimbrite breccias, composed of angular - sharply angular basaltic andesite, compact - scoriaeous, embedded within ash matrix and pumiceous lapilli of the Lampung Tuff. Location 13, Way Andeng, coordinate 5^0 49' 42.4" S & 105^0 41' 31.5" E.

Volcano foot and Kalianda City, there are three hot springs, among others Way Belerang that becomes a hot spring tourist object. At the southern part of the Rajabasa Volcanic foot, a hot spring can also be found at Wartawan Beach tourist object.

The landscape of lava flow originating from the Rajabasa Volcano forms a hill ridge sloping down from the above to the foot. In the Rajabasa foot at the beach area, the lava forms massive boulders sticking out into the sea. The Rajabasa volcanic rocks are dominated by lava flow consisting of basalt, basaltic andesite, and andesite, glassy, aphanitic and porphyritic with fine- to medium-grained plagioclase and pyroxene phenocrysts. The lava is compact to vesicular, forming sheeting to columnar joint. However, the outer side occurs as blocky lavas or autoclastic breccias (Figure 10). In detail, a segregation occurring between grey and oxidized brownish red andesitic lava tends to show a layering-like structure.

Based on the satellite image, lava in the Rajabasa Volcanic Complex is not only originated from the central crater at the peak, but also from the slope and foot eruptions that can be grouped into parasitic or monogenetic volcano. The monogenetic volcanoes appear almost on all flanks and foot of the Rajabasa Volcano as well as on the plateau around it, but still in the Pre-Rajabasa Caldera depression. In Kalianda Town itself, the monogenetic volcano is present as small hills, among others the one that is used for the Chinese cemetery and the other one located in the front of the Mine Service, South Lampung Regency. In general, the monogenetic volcanic rocks are composed of andesitic-basaltic lava, similar to lava as the result of the peak crater eruption of Rajabasa Volcano.

A different appearance occurs at the east foot of Rajabasa Volcano because at that location pyroclastic rocks crop out at a narrow circular hill ridge where on both sides there are very deep valleys. Based on the satellite image (Figure 2), the circular hill has a very steep slope facing north - west or facing Rajabasa volcanic peak, while the east - south slope is relatively slightly sloping. It is

Figure 10. Blocky lavas cropping out in Rajabasa Volcano Complex; a. In location 15, coordinate 5⁰ 49' 31.3" S & 105⁰ 40' 58.9" E; b. In Cantik Village, location16, coordinate 5⁰ 48' 15.8" S & 105⁰ 35' 04.6" E; c. In Kekiling Village, location 17, coordinate 5⁰ 43' 44.1" S & 105⁰ 38' 55.0" E; d. In Kalam Village, location 18, coordinate 5⁰ 45' 45.7" S & 105⁰ 39' 47.3" E.

composed of scoriae breccias with brown - greyish brown weathered tuff matrix. Scoriae fragment looks banded, blackish grey and white. The pyroclastic rock may form a cinder cone.

Suswati *et al.* (2001) carried out a geological mapping of the Rajabasa Volcano in detail. The Rajabasa volcanic rocks are divided into three unit groups: 1. Sulphuric Volcanic Product, 2. Flank Eruption Product, and 3. Rajabasa Volcanic Product. The rocks are dominated by lava flow composed of basaltic andesite to high silica andesite (53.25 - 62.35 % SiO_2). While Sinulingga (2000) reported that the lava of Rajabasa Volcano was basaltic to andesitic (50.07 - 59.63 % SiO_2) in composition.

In Way Andeng flow, southeast of Totoharjo Village, location 24, a pyroxene andesite lava of the Rajabasa Volcano crops out very well overlying the Lampung Tuff and is intruded by a basaltic-andesitic dike (Figure 11). Pyroxene andesitic lava is grey in colour, but in a contact with dike the colour changes to become brick red - brownish, due to baking effect; porphyritic texture with medium-grained pyroxene phenocryst (Ø ≤ 1 cm) of ± 20 %, embedded in aphanitic groundmass. The lava is compact to vesicular. The basaltic-andesitic dike has a tabular shape, stretching towards west - east direction (N 97⁰ E), 3 m but bigger to the east direction forming a lava hill. The dike has aphanitic - porphyritic dark grey colour with fine- to medium-grained pyroxene embedded in aphanitic groundmass. Presumably, the dike then formed a lava cone (dome?) as a monogenetic eruption at the foot of Rajabasa Volcano, but both were originated from the same magma. The occurrence of dike cutting through the Rajabasa Volcano lava shows that the eruption activities at the peak crater coincided with or followed by the eruption at the flanks and foot of Rajabasa Volcano as the manifestation of volcanism after the construction of Pre-Rajabasa Caldera.

The primary eruption of the Rajabasa Volcano were then followed by the secondary ones, that is the formation of laharic breccias and fluvial sediments (conglomerate breccias and cross-bedded sandstone)

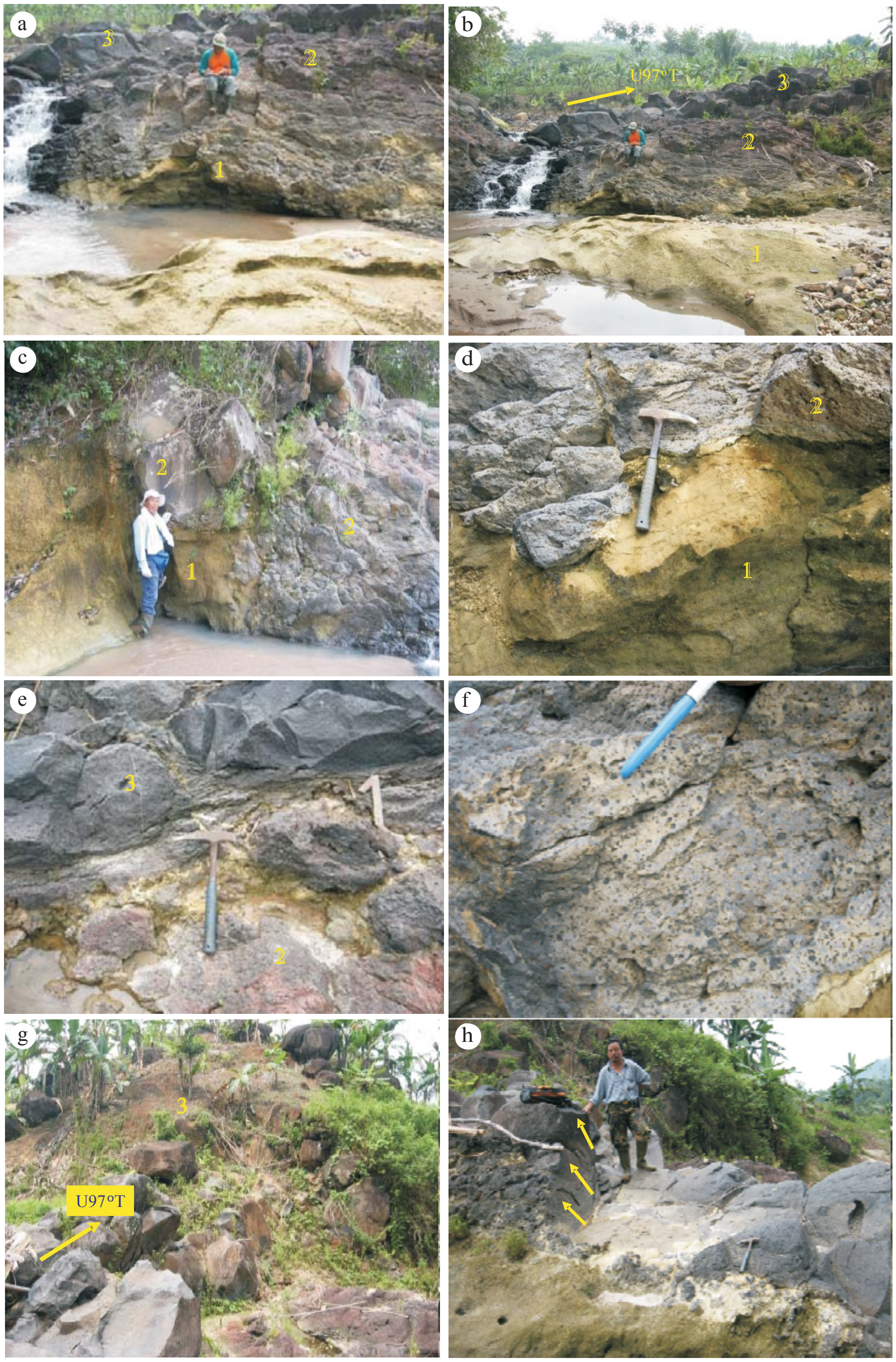

Figure 11. A contact between the Lampung Tuff (1), pyroxene andesitic lava of the Rajabasa Volcano (2) and basaltic-andesitic dike (3), in Way Andeng, SE part of Totoharjo Village, location 12, coordinate 5^0 49' 11.0" S & 105^0 41' 38.3" E. a & b. A contact between the Lampung Tuff (1), pyroxene andesite lava of the Rajabasa Volcano (2), and basaltic-andesitic dike (3); c & d: Close up is a contact between the Lampung Tuff (1) under pyroxene andesitic lava above (2); e. Close up is a contact between pyroxene andesitic lava (2) with pyroxene basaltic andesitic dike (3). The dyke intrusion caused a baking effect on the lava; f. Close up is pyroxene andesitic lava showing porphyritic texture with medium- to coarse-grained pyroxene phenocryst, black, prismatic, embedded within aphanitic groundmass; g. Basaltic andesite dike forming a lava cone is suggested to be the remain of lava dome uprising at the surface as monogenetic volcanic eruption at the foot of Rajabasa Volcano; h. A vertical movement (arrow direction) of the dike, the centre part massive, the edge part brecciated (autobreccia/autoclastic).

commonly cropping out in the plain area around the Rajabasa Volcano. At the Way Andeng flowage, the secondary deposit of Rajabasa Volcano was clearly seen to rest on the Lampung Tuff.

Discussion

The evolution and cycle of volcanism seem to occur in the studied volcano activities. The activities were initiated by the construction of the cone of Rajabasa Volcano (Figure 12.1), as the development period or the construction phase of a composite volcanic cone. At this period, the eruption produced andesitic lava flow and pyroclastic breccias (and tuff). The paleovolcano then was dormant, so soil and oxidized rock (Figure 5) and erosional surface (Figures 6a & b) were formed at some places within a terrestrial environment. While the volcano was dormant for a long time, the magma below undergone differentiation from an andesitic to become rhyolitic composition. The magma differentiation is suggested to occur step by step from andesitic, dacitic, and then rhyolitic composition in accordance with the Bowen Reaction series, whilst volatile matter separation from the magma fluid took place. The volatile matter or magma/volcanic gas occupied the upper part while the fluid matter was at the lower part of the magma chamber of Pre-Rajabasa Volcano. The longer, the more volatile produced led to the higher pressure below the caprock of the Pre-Rajabasa composite volcanic cone. A very huge eruption would take place if the pressure of the volatile matter was higher than the cap rock above. At that time, the rhyolitic magma was outpoured onto the surface as pyroclastic matter consisting of voluminous pumice and volcanic ash along with rhyolitic bomb and volcanic block. Along with those andesite boulders of old rocks were also outspored forming co-ignimbrite breccias. This event can be regarded as a destruction period of the composite cone of Pre-Rajabasa Volcano leading to the construction of Pre-Rajabasa Caldera (Figure 12.2). The Pre-Rajabasa Caldera probably has a diameter of ± 25 km reaching the sea at the west side of the present Rajabasa Volcano (Figure 2). The development of the composite volcanic cone till the destructive period and the construction of Pre-Rajabasa Caldera are regarded to be the first volcanism cycle.

The second volcanism cycle began with the appearance of many new eruptions inside the Pre-Rajabasa Caldera basin (Figure 12.3). Some of the new eruptions formed a monogenetic volcano, but some others were continuing to grow and develop to become the cones of Rajabasa composite volcano as can be seen now (Figure 12.4). The change of the peak eruption of the Rajabasa Volcano at the W NW–E SE direction is presumed to be controlled by a deep crack structure so most magma was forced to come out through the crack zone. The eruption activities of the centre of Rajabasa Volcano were followed by the flank and foot eruptions around the depression of the Pre-Rajabasa Caldera. To know the age of the evolution from the Pre-Rajabasa Volcano till the present Rajabasa Volcano, it is suggested to carry out a radiometric analysis. The volcanism activities of the Rajabasa Volcano can be compared with the volcanism of Ijen Volcano in East Java and Batur Volcano in Bali.

The Lampung Formation or Lampung Tuff is widely distributed to the north of Bandar Lampung City and even West Lampung Regency, Lampung Province (Andi Mangga *et al*., 1994). This condition tends to cause a question: Whether the Lampung Tuff originated from one caldera source, that is the Pre-Rajabasa Caldera, or from some other volcanic calderas in Lampung Province? This question comes up because so far the geological study is based on the lithological similarity (rhyolitic tuff) and lithostratigraphy. Referring to the result of a research in the Southern Mountain, Yogyakarta, Central Java, towards pumice breccia and tuff known as the Semilir Formation (Surono *et al*., 1992) which is also distributed widely and thickly, it is known that in that area at least there are three volcanic caldera sources: Parangjoho-Songputri Caldera (Bronto *et al.,* 2009), Gajahmungkur Caldera (Hartono, 2010), and Sindet Caldera (Bronto, 2010). Meanwhile, in Banten located closer to the Rajabasa Caldera compared to Bandar Lampung, there is Dano Caldera producing Banten Tuff (van Bemmelen, 1949; Rusmana *et al*., 1991; Santosa, 1991). Occurring close to each other, in Bali there are Batur and Buyan-Bratan Calderas (Bronto and Sudarsono, 2003), both producing large volume of tuff and pumice. In the western part of Lampung, there are many depressions suggested to have been volcanic calderas, among others:

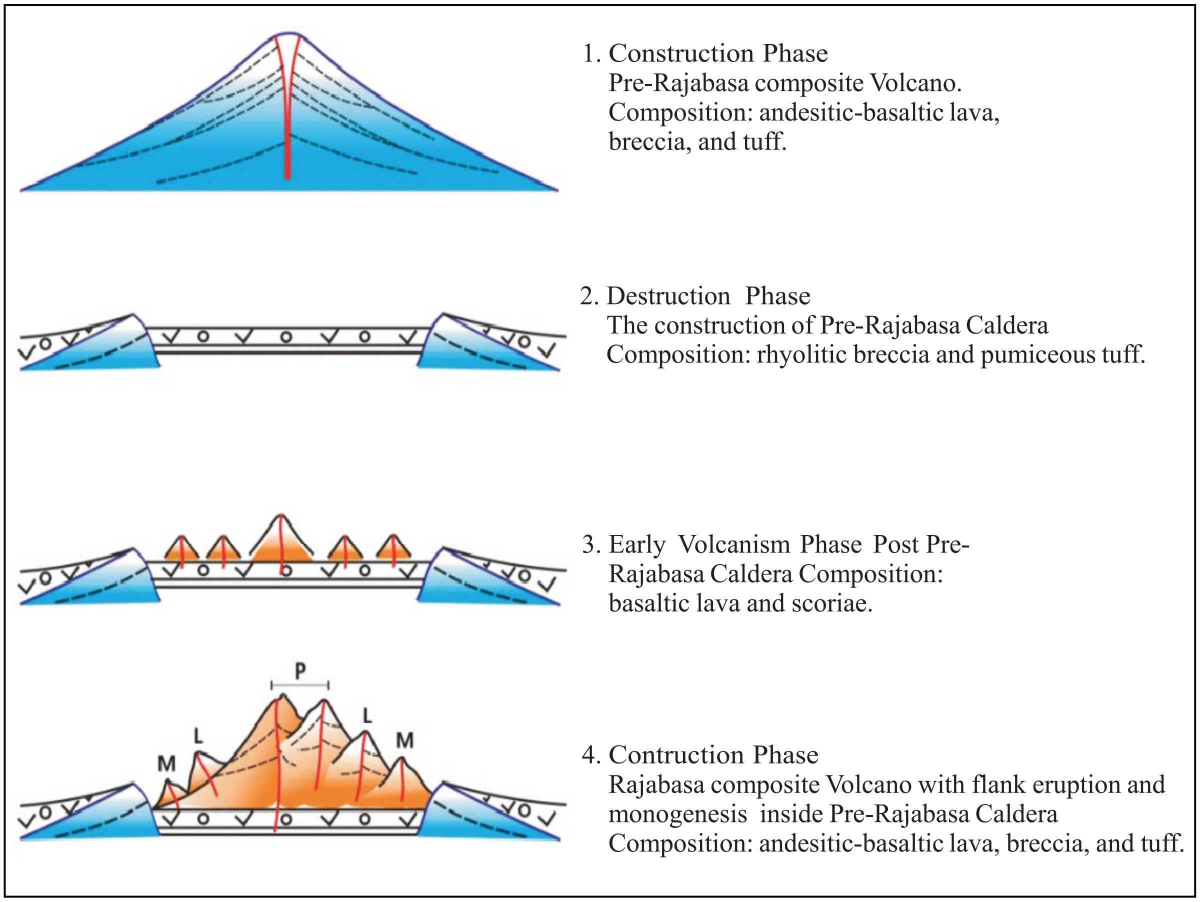

Figure 12. A sketch of evolution model of the Rajabasa Volcano; 1. Construction of composite cone of the Pre-Rajabasa Volcano; 2. Destruction of the Pre-Rajabasa volcanic cone, causing the form of Pre-Rajabasa Caldera; 3. Primary appearance of volcanism inside the Pre-Rajabasa Caldera forming many monogenetic volcanoes; 4. Construction period of Rajabasa volcanic composite cone as the centre of the eruption (P), still being followed by flank (L) and foot eruption as a monogenetic volcano (M).

Antatai, Sekincau-Belirang, Suoh, Hulubelu, and Gedungsurian (Simkin and Siebert, 1994; Bronto and Sudarsono, 2003). Based on that consideration, the Lampung Formation is assumed to be derived from some volcanic caldera sources. To know the source of the volcanic caldera it is suggested that further researches should volcanic geologically be carried out.

Conclusions

The volcanism activities of Rajabasa Volcano were commenced with the development of Pre-Rajabasa volcanic composite cone, which then it was followed by the volcanic cone destruction period, so the Pre-Rajabasa Caldera with ± 25 km in diameter was formed. The present Rajabasa Volcano coincidently rose with the eruption of the slope and monogenetic volcano inside the Pre-Rajabasa caldera depression as the second development period of the composite cone. From the beginning of the rise of the volcano till the development period of composite volcanic cone, both the Pre-Rajabasa Volcano and Rajabasa Volcano, their forming-rocks are basaltic-andesitic lava, volcanic breccia, and tuff. As a subvolcanic rock, at the lower part, it occurs as basaltic-andesitic dikes. The Rajabasa Volcano itself has moving eruption points at WNW-ESE directions, suggested to be controlled by subsurface faults or weak zones. A huge eruption forming the Pre-Rajabasa Caldera produced rhyolitic Lampung Tuff as pyroclastic material with flow, fall, and surges mechanisms also known as pyroclastic density currents.

Radiometric dating is required to know the activity age of the Pre-Rajabasa Volcano, Pre-Rajabasa Caldera, and Rajabasa Volcano itself. It is presumed that the Lampung Tuff was derived from some volcanic caldera sources, of which its occurrence still needs a further research on volcanic geology.

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