Bulletin of Geology
e-ISSN 2580-0752
e-ISSN 2580 - 0752
Fakultas Ilmu dan Teknologi Kebumian
Institut Teknologi Bandung
www.buletingeologi.com

VOLCANOSTRATIGRAPHY IN THE LOKON VOLCANO AREA AND ITS SURROUNDINGS, NORTH SULAWESI

Kevin Gerald Senduk[1], Mirzam Abdurrachman[1*]

1. Geological Engineering Study Program, Faculty of Earth Science and Technology, Bandung Institute of Technology, Bandung
Email: mirzam@gl.itb.ac.id

Sari - Gunung Api Lokon adalah gunung api Kuarter aktif yang berada di busur gunung api Sulawesi – Sangihe. Penelitian ini dilakukan untuk menjelaskan stratigrafi batuan gunung api Lokon berdasarkan analisis geomorfologi dan karakteristik petrologi. Berdasarkan analisis geomorfologi, area Gunung Lokon dibagi menjadi sembilan domain geomorfologi (Kayawu, Woloan, Kamasi, Irang, Lokon, Tatawiran, Galean, Kinilow dan Empung) pemisahan dilakukan berdasarkan pola kelurusan topografi, relief dan pola sebaran topografi. Berdasarkan deskripsi litologi lapangan, litologi dibedakan menjadi 18 satuan geologi berupa aliran lava, aliran piroklastik, jatuhan piroklastik dan aliran lumpur. Satuan batuan Gunung Lokon dan sekitarnya sesuai SSI (Sandi Stratigrafi Indonesia) diklasifikasikan kedalam Khuluk Tatawiran, Khuluk Kinilow, Khuluk Empung dan Khuluk Tou Lokon. Khuluk Kinilow didominasi oleh endapan piroklastik dengan komposisi basal bertekstur skorius, sedangkan Khuluk Empung didominasi oleh aliran lava basal. Khuluk Tou Lokon terdiri dari 3 Gumuk yaitu Gumuk Lokon yang didominasi oleh aliran piroklastik, Gumuk Irang yang dimonasi oleh aliran lava dengan tekstur holohyalin dan Gumuk Tompuluan yang didominasi oleh jatuhan piroklastik. Fasies gunungapi Gunung Lokon dibagi menjadi Fasies Proksimal Tatawiran, Sentral Tatawiran, Fasies Proksimal Tatawiran, Fasies Sentral Kinilow, Fasies Proksimal Kinilow, Fasies Medial Kinilow, Fasies Sentral Empung, Fasies Proksimal Empung, Fasies Sentral Lokon, Fasies Proksimal Lokon, Fasies Midial Lokon, Fasies Sentral Irang, Fasies Proksimal Irang, Fasies Sentral Tompuluan dan Fasies Proksimal Tompuluan.

Kata Kunci: Domain, gunung api, Lokon, SSI, vulkanostratigrafi.

Abstract *- Lokon Volcano is an active Quaternary volcano located in the Celebes - Sangihe Volcanic Arc. This study aims to explain the stratigraphy of Lokon's volcanic rocks based on geomorphological analysis and petrological charaterization. The Lokon Volcano area is devided into nine distinct geomorfological domains (Kayawu, Woloan, Kamasi, Irang, Lokon, Tatawiran, Galean, Kinilow, and Empung) based on patterns of topographic straightness, relief, and topographic distribution. Field observations have led to the classification of the rock units into 18 geological entities, including lava flows, pyroclastic flows, pyroclastic falls, and mudflows. Volcanology units of Lokon Volcano and its surroundings according to ISC (Indonesian Stratigraphic Code) are classified into Crown Tatawiran, Crown Kinilow, Crown Empung, and Crown Tou Lokon. Crown Kinilow predominantly comprises scorious textured basalt pyroclastic deposits, whereas Crown Empung is mainly characterized by basalt lava flows. Crown Tou Lokon consists of three hummocks, namely Lokon, dominated by pyroclastic flows; Irang, dominated by lava flows with holohyalin textures; and Tompuluan, dominated by pyroclastic falls. The volcanic facies of Lokon Mountain are further classified into Tatawiran Proximal Facies, Kinilow Central Facies, Kinilow Proximal Facies, Kinilow Medial Facies, Empung Central Facies, Empung Proximal Facies, Lokon Central Facies, Lokon Proximal Facies, Lokon Medial Facies, Irang Central Facies, Irang Proximal Facies, Tompuluan Central Facies, and Tompuluan Proximal Facies.*

Keywords*: Domain, volcano, Lokon, ISC, volcanostratigraphy.*

1. INTRODUCTION

Mount Lokon is an active volcano located in Tomohon City (Figure. 1), North Sulawesi. Mount Lokon has an elevation of ±1579.5 meters above sea level (masl). Adjacent to the northern part of Mount Lokon lies Mount Empung, which is no longer active, and between the north side of Mount Lokon and the south side of Mount Empung, there is an active crater known as Tompuluan Crater.

Researchers in this area have the opportunity to explore the potential of Mount Lokon's natural resources, starting with a comprehensive analysis of

BULLETIN OF GEOLOGY, VOL. 7, NO. 2, 2023
DOI: 10.5614/bull.geol.2023.7.2.2.

the volcanostratigraphy of the volcanic constituent rocks. Currently, there is an operating rock mine (Quarry) on the mountain, indicating that the natural resources of Mount Lokon have already been subject to exploitation.

Volcanostratigraphy is a scientific discipline dedicated to studying the sequence of rocks, particularly volcanic rocks. Its primary purpose is to identify relationships between the products of volcanic eruptions, which in turn provide valuable insights into the geological evolution of the area.

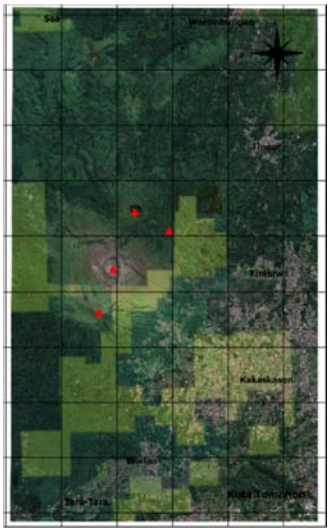

Figure 1 Lokon Volcano situated in the western part of Tomohon City.

The anticipated outcome of this research is to serve as a foundation for various applied geological sciences. For instance, the presence of hot springs in the Kinilow area area could be investigated as a study of hydrothermal manifestations. Furthermore, due to Tomohon City's geographical position between Mount Lokon and Mahawu, there are potential opportunities for disaster mitigation studies in the surrounding region or for designating the area as a geotourism study site.

2. REGIONAL GEOLOGY

Geologically, Mount Lokon is located on the volcanic arc of the North arm of Sulawesi (Hamilton, 1979). The basement rocks for the North Sulawesi area consist of pre-Cretaceous metamorphic rocks, which are also exposed in the Palu area (Ratman, 1976; Sukamto et al, 1973; 1975). The Pliocene–Pleistocene rocks in western North Sulawesi exhibit characteristics of agglomerates, breccia, lava, and tuff (gray-lapilli) composed of andesitic–dacitic–basaltic material. On the other hand the eastern part of North Sulawesi is characterized by volcanoclastic such as pumice, lapilli pumice, breccia, ignimbrite, andesitic-trachytic lava, and tuff. Volcanoes in this arc, including Mount Lokon are still actively producing agglomerate material, lava, tuff, hot clouds, and lava deposits. The composition of these volcanic materials generally ranges from andesite (hypersthene–augite) to basalt (olivine – augite) (Surono and Hartono, 2015).

3. METHODOLOGY

The study was conducted using three stages, namely: (1) remote sensing stage, (2) field observation stage, and (3) laboratory analysis.

During the remote sensing stage, DEM image processing was performed using a digital analysis method based on the domain division by Fornaciai *et al.* (2010). This method was chosen because it allows for the classification of volcanic products based on their relative lifespan, ranging from old to young. Each domain possesses similar geomorphometric characteristics and possesses similar the straightness of the rose diagram (Figure 2).

The field observation stage involves the classification of rock units based on the texture and structure of volcanic rocks. This stage also entails collecting rock samples for subsequent laboratory analysis. Furthermore, the volcanic products are classified into stratigraphic units in accordance with the Indonesian Stratigraphic Code by the Indonesian Association of Geologists (1996). At this stage, the facies distribution at each level of the volcano will be determined based on the products obtained from the field observation.

BULLETIN OF GEOLOGY, VOL. 7, NO. 2, 2023
DOI: 10.5614/bull.geol.2023.7.2.2.

4. RESULT

Remote Sensing

Based on the results of the Domain division, the study area is divided into nine domains (Figure. 2), ordered from the oldest to the youngest.

Domain I

Domain I is predominantly located in the southwestern to western part, representing the older section of Mount Lokon, specifically Mount Tatawiran. The southern area of Domain I appears to have undergone slight flattening due to significant fluvial processes.

Domain II

Domain II extends across the southern region, following a northward flow direction and adjacent to Domain I. It is thought that the origin of Domain II is similar to that of Domain I, but with the presence of more resistance rock.

Domain III

Domain III extends from the Kinilow to Kali section, characterized by a predominant NE topography. The formation of caldera walls can be identified through satellite imagery or field observations, indicating the source of the eruption of the material. This domain exhibits numerous structures, notably marked by the presence of hot springs. Additionally the presence of the straightness of the Kali River supports the existence of the Kali Fault (Poedjoprajitno, 2012), with the identification of Paslaten Fault that allows for an extension of the Kali Fault. Furthermore, the presence of straightness in this domain contributes to the formation of valleys. The deformation of rocks is evident in the Warembungan area, particularly in the "balapis rock" garden. It is worth noting that this fault intersects domain III but does not intersect domain V.

Domain IV

Domain IV covers the Warembungan to sea area, featuring a dominant NW topography. The formation of the caldera wall can be identified through satellite imagery. Notably, from the center of this eruption, two distinct domains formed at different times can be observed.

Domain V

This domain is widespread in the area of Kakaskasen and its surroundings. The craters of Mount Lokon and Tou Lokon Crater are clearly visible through satellite imagery and field observations. The topographical distribution in this domain spreads from SE to NW. The topographic patterns within this domain are relatively in domains III and IV.

Domain VI

The eruption that generated domain VI led to the destruction of the Tou Lokon crater wall toward the south. The distribution of material generally follows a northwestward direction, but the flow shift to the southwesr due to the presence of the caldera edge of Mount Tatatwiran (domain I).

Domain VII

This domain constitutes a parasitic dome situated on the southern slopes of Mount Lokon. This dome extends in a southerly direction following the slopes below.

Domain VIII

Domain II shares similar characteristics with Domain II. Both domains II and VIII are bounded by the Matani Fault.

Domain IX

Domain IX exhibits flow formation spreading across the Kinilow area, encompassing the boundary between domain V and domain III. Topographic formations extend from southeast to northwest.

BULLETIN OF GEOLOGY, VOL. 7, NO. 2, 2023
DOI: 10.5614/bull.geol.2023.7.2.2.

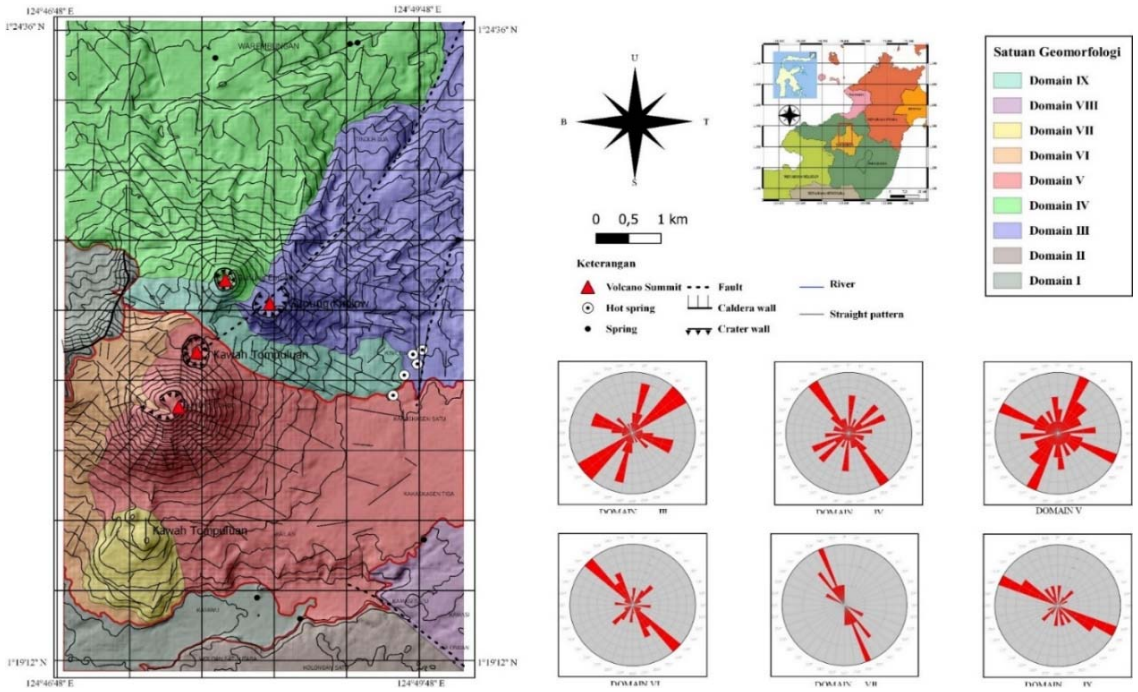

Figure 2 The geomorphology of the Lokon Volcanic Complex, along with its domains is depicted by the straight patterns illustrated in the rose diagram. The rose diagram displays the dominant direction of each domain.

Field Observation

Based on field observation, there are 18 rock units (Figure 3 – 5). Common characteristics include basalt and lapilli lava with scorious structures. Rock units from the oldest to the youngest layers are as follows:

1. Tna - (Kayawu tuff breccia) is spread over the Kayawu to Tara-Tara area. As we move upwards, the rock fragments transition to being composed of igneous rock fragments, while the lower part of the unit consists of floating rocks
2. Kl1 – This unit comprises basalt lava with a porphyritic texture, characterized by a distinctive sheeting fracture structure. On the racing rock garden, coarser-sized basalt can be found.
3. Ka – The black pyroclastic deposits are lapilli-sized (2 – 5 mm), and consist of generally unconsolidated grains composed of fragments of scorious-structured rocks.
4. Kl2 – This unit comprises black andesite lava with a fine granularity and vesicular texture, resulting from a central eruption.
5. is scattered in the Warembungan – Sea area exhibits a characteristic flow texture and a scorious – vesicular structure at the top of the unit.
6. El2 – This andesite lava has a finer crystalline size compared to El1 and features a massive general structure.
7. El3 – The reddish-black basaltic lava with an aphanitic texture is scattered in the Sea area and displays a vesicular structure.
8. La1 – The lower part of this unit consist of volcanic breccia with a brown tuff matrix containing igneous rock fragments, while and the upper part consists of a layer of lapilli-sized pyroclastic deposits – unconsolidated blocks and fragments showing a characteristic pyroclastic structure.

BULLETIN OF GEOLOGY, VOL. 7, NO. 2, 2023
DOI: 10.5614/bull.geol.2023.7.2.2.

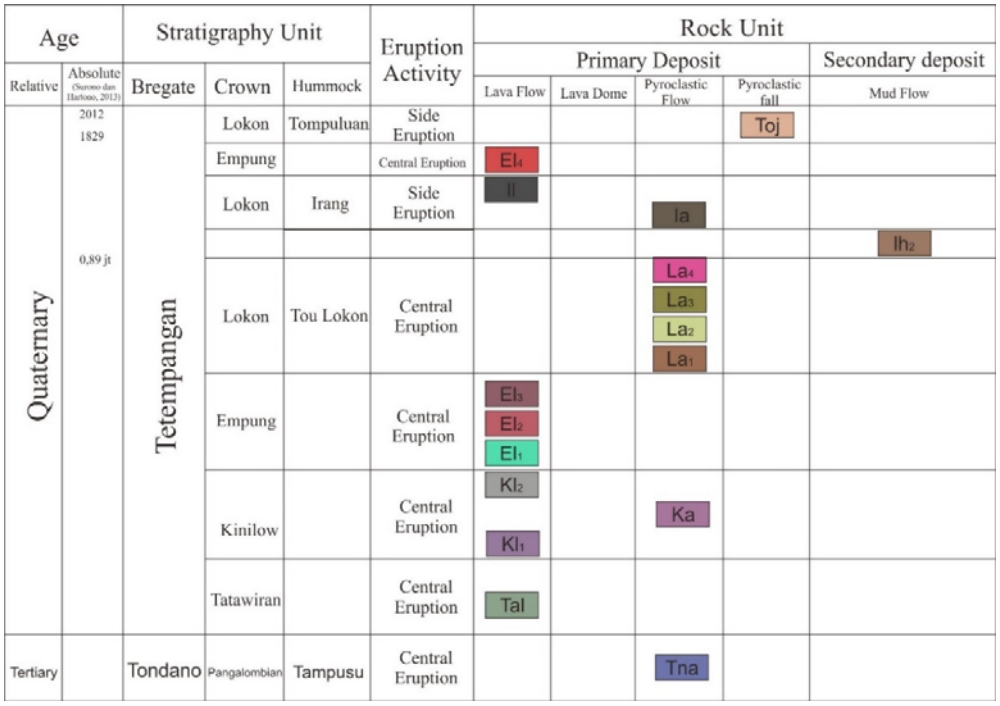

Figure 3 Volcanostratigraphy of Lokon Volcanic Complex referring to the Indonesia Code of Stratigraphy of Volcano stratification (1996).

9. La2 – This unit comprises layers of lapilli-sized pyroclastic deposits, of medium size and sorting. Each outcrop generally displays uniform consistency, and basaltic lava inserts are present. It is widespread in the area of Kayawu to Kakaskasen.
10. La3 – The lower part of the unit consists of an unconsolidated layer of black–red scoria, while the middle part shows an alternation between lava and scoria. The upper part is dominated by basaltic lava with a vesicular structure. Lava interspersions can be clearly observed in Tompuluan Crater.
11. La4 – This layer is dominated by reddish-black scoria. As it ascends, the size of the rocks becomes smoother, but the scoria structure is still evident. Organic components preserved due to the flow mechanism were found.
12. Ia – black tuff exhibits characteristics of very hard compactness and the presence of obvious glassy fragments.
13. Il – Also known as "bakaca stone," this is obsidian lava (glassy) with two characteristics. The bottom generally indicates the presence of obsidian banding, while the upper part lacks such features and consists of uneven fragments.
14. Toj – This unit consists of fall-type pyroclastic deposits from the eruption of Tompuluan Crater, comprising blocks and bombs with cauliflower fracture characteristics. Ash pumice stones and glassy block fragments are also present.

BULLETIN OF GEOLOGY, VOL. 7, NO. 2, 2023
DOI: 10.5614/bull.geol.2023.7.2.2.

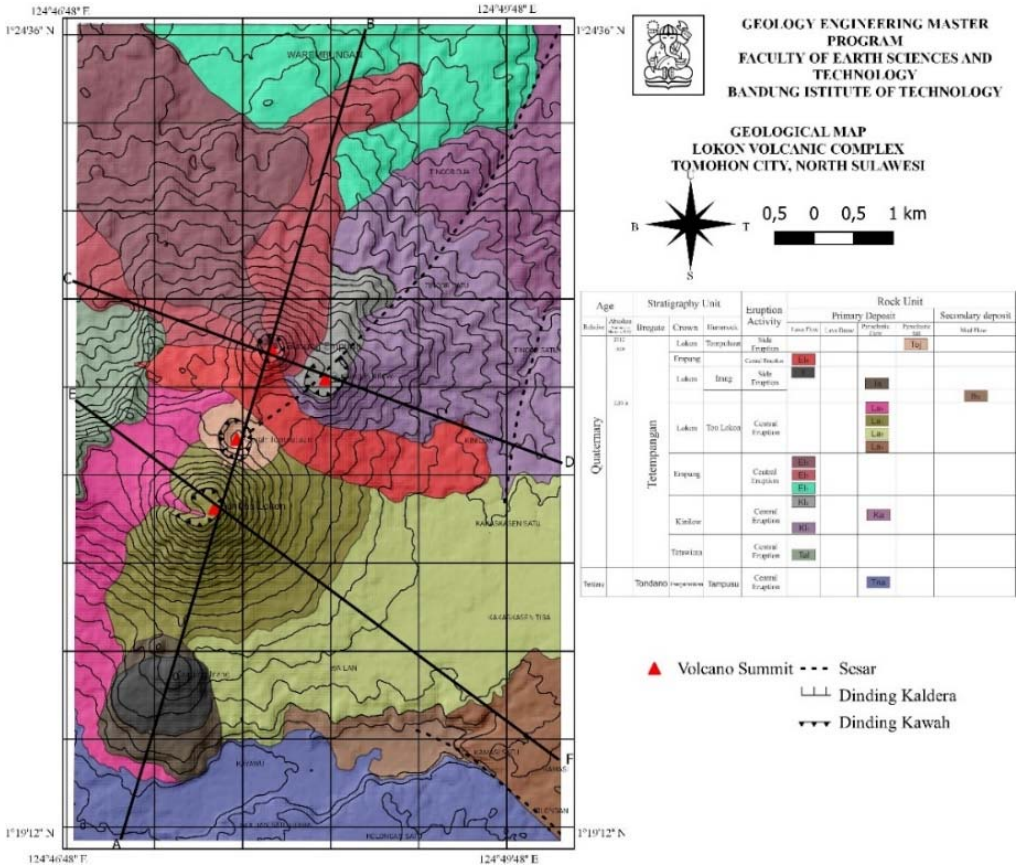

Figure 3 Geological map of Lokon Volcanic Complex. The colors on the map correspond to the colors used in the volcanostratigraphy table (Figure 3).

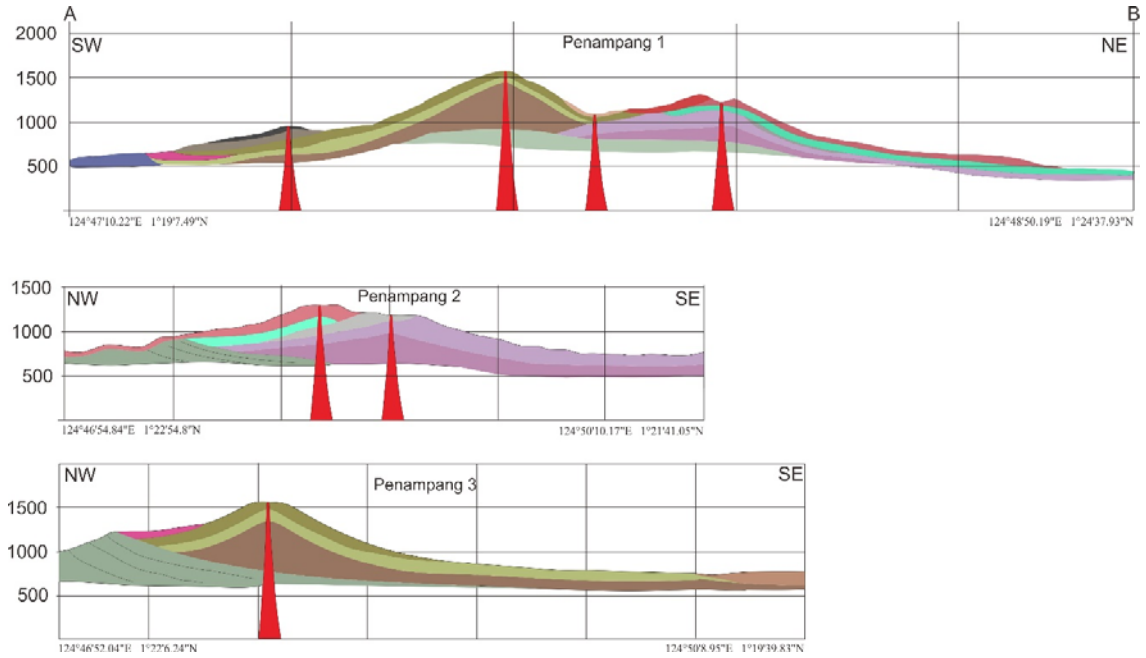

Figure 4 Cross section of the mapped area corresponding with the black line in the geological map (Figure 4).

BULLETIN OF GEOLOGY, VOL. 7, NO. 2, 2023
DOI: 10.5614/bull.geol.2023.7.2.2.

Laboratorium analysis

Laboratory analysis was conducted to examine and validate rocks at a microscopic scale, and specific analysis used is rock petrography. A total of 21 petrography incision analyses have been performed.

The Kinilow Crown primarily comprises lava (Figure 6) and pyroclastic (Figure 7). Based on the observation, the lava is identified as augite-andesite and the pyroclastic material is composed of lithic lapilli deposit. The Empung Crown is predominantly composed of lava flow with a higher content of mafic minerals. These lava flows exhibit larger phenocrysts (Figure 8) compared to the lava found in the Kinilow Crown lava. The Lokon Crown is predominantly composed of pyroclastic flow deposits (Figure 9), with some lava present in the upper part of the Tou Lokon Hummock stratigraphy. The lava in the Kinilow and Empung Crowns is dominantly andesite, whereas the Lokon Hummock is primarily composed of basalt lava (Figure 10).

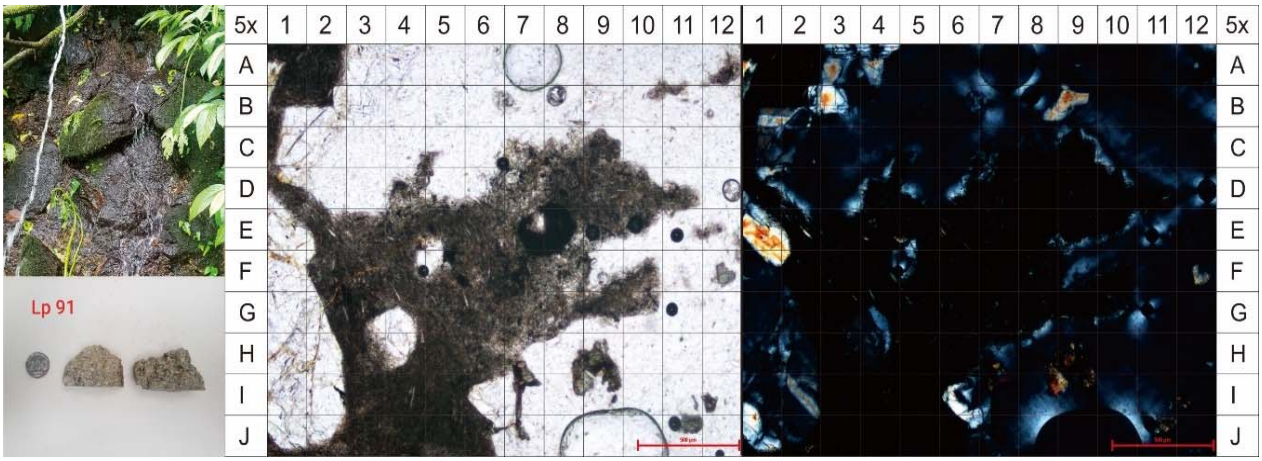

Figure 5 A petrography photo of lava from the Kinilow Crown showing high volume of vesicular structure.

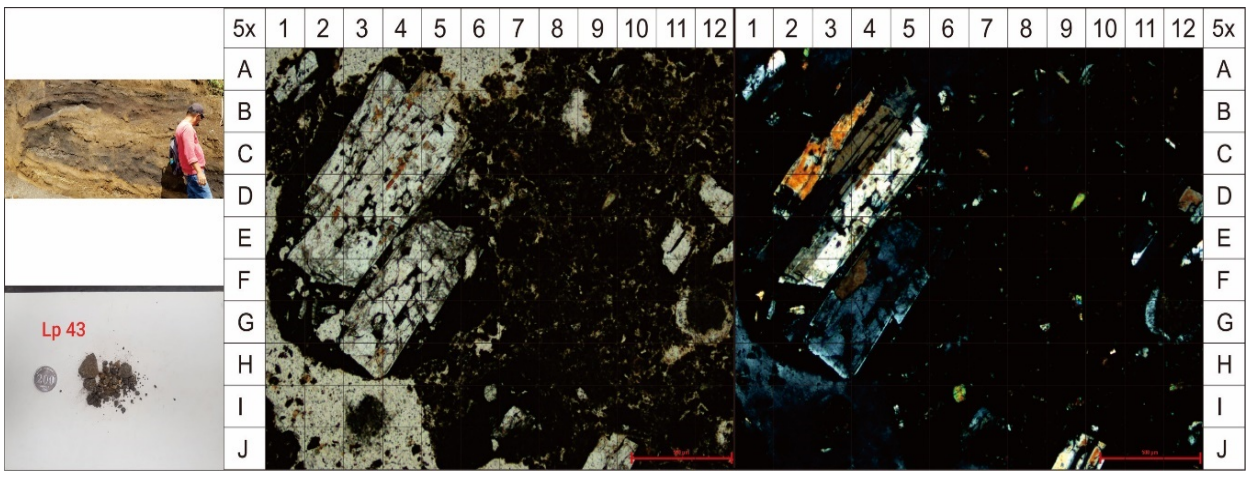

Figure 6 A petrography photo of Kinilow Crown pyroclastic lithic lapilli fragments. The sample shows coarse lapilli rich in minerals such as plagioclase.

BULLETIN OF GEOLOGY, VOL. 7, NO. 2, 2023
DOI: 10.5614/bull.geol.2023.7.2.2.

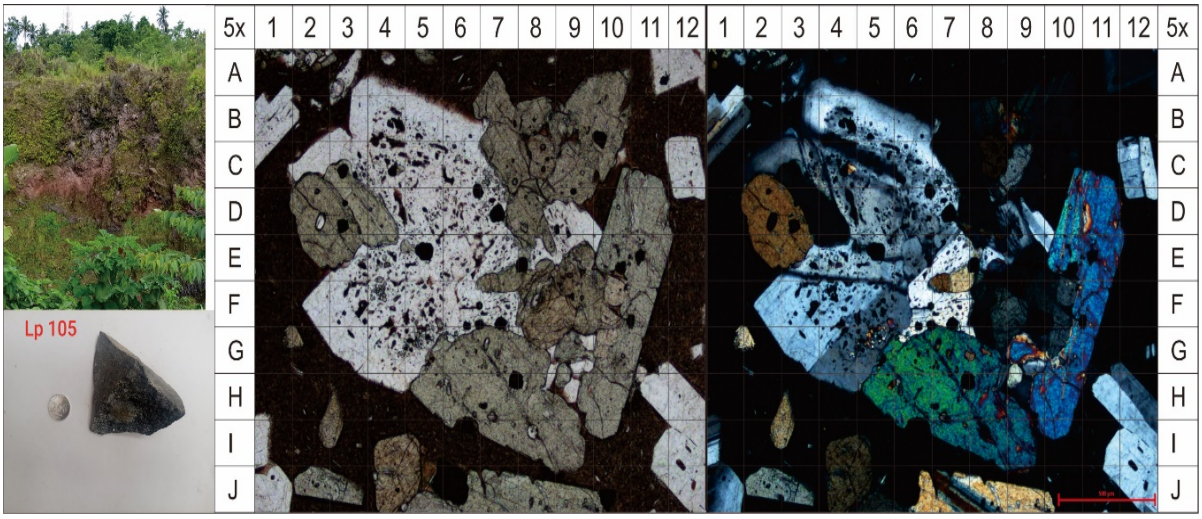

Figure 7 Representation of Empung Crown Lava shows a higher abundance of augite-rich andesite than compared to Crown.

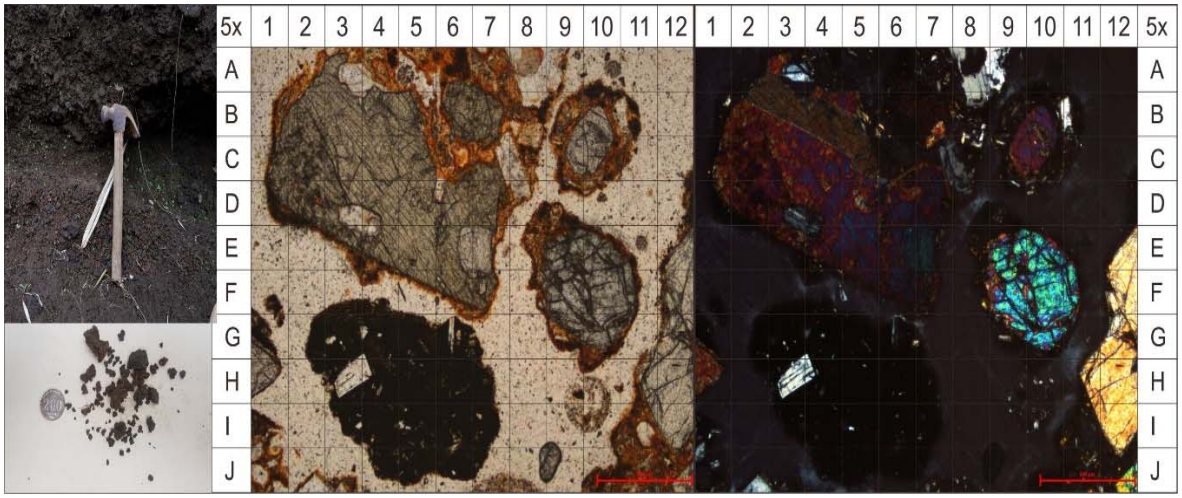

Figure 8 A petrography of the lapilli fragment that comprises Lokon Crown reveals a high content of mafic mineral such as augite.

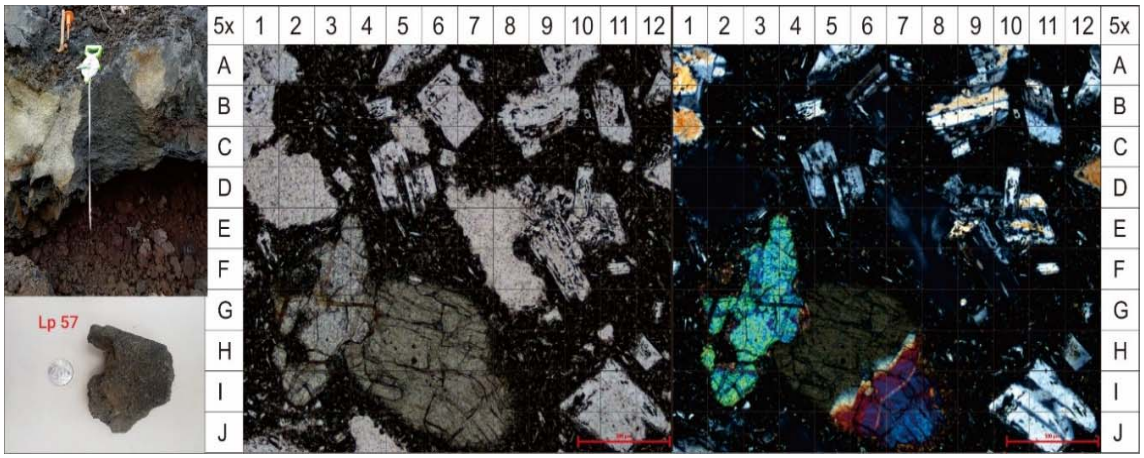

Figure 9 A petrography photo of basalt lava representing Lokon Crown Lava.

BULLETIN OF GEOLOGY, VOL. 7, NO. 2, 2023
DOI: 10.5614/bull.geol.2023.7.2.2.

Lokon Volcanic Complex volcanic Facies

The division of volcanic facies is based on Bogie and MacKenzie (1996) aimed at explaining the distribution of each volcanic product to its respective eruption source. As a result, the volcano system in this area is divided into the following: Tatawiran Volcano System, the Kinilow Volcano System, the Empung Volcano System, the Lokon Volcano System, the Irang Parasitic Volcano System, and the Tompuluan Parasitic Volcano System (Figure 11).

Tatawiran Volcano System

1. Tetempangan Proximal Facies
   Mostly located in the west and consist of lava from Tetempangan Volcano.

Kinilow Volcano System

1. Kinilow Central Facies
   Located on the summit of Mount Kinilow and composed of andesitic lava. The eruption's influence caused the northern part of the crater ring to break.
2. Kinilow Proximal Facies
   Extending northeastward, composed of pyroclastic flows and lava flows.
3. Kinilow Medial Facies Scattered in the southern part and consists of mudflows.

Empung Volcano System

1. Empung Central Facies
   It is located west of Kinilow peak and still shows a circular crater ring.
2. Empung Proximal Facies
   It is spread over the Warembungan to Sea area and is composed of lava flows with distribution
   .

from the north to the northwest. Partial lava flows are dispersed into Kinilow.

Lokon Volcano System

1. Lokon Central Facies
   The peak of Mount Lokon is located to the south of Tompuluan Crater.
2. Lokon Proximal Facies
   Extending from the Kakaskasen area to Tara-Tara, composed of pyroclastic flows and lava flows.
3. Lokon Medial Facies
   It is scattered in the Kamasi area, composed of mudflows containing igneous rock fragments.

Irang Parasitic Volcano System

1. Irang Central Facies
   Located to the south of Mount Lokon, forming a geomorphological isolated contour signifying an intrusion. Which composed of obsidian. A side eruption of Mount Lokon.

2. Irang Proximal Facies
   It is composed of obsidian and pyroclastic flows with distribution directly to the south.

Tompuluan Parasitic Volcano System

1. Tompuluan Central Facies
   It is located between Mount Lokon and Mount Empung, forming a negative volcano. A volcano that is still active today.
2. Tompuluan Proximal Facies
   It is composed of deposits from the Tompuluan eruption

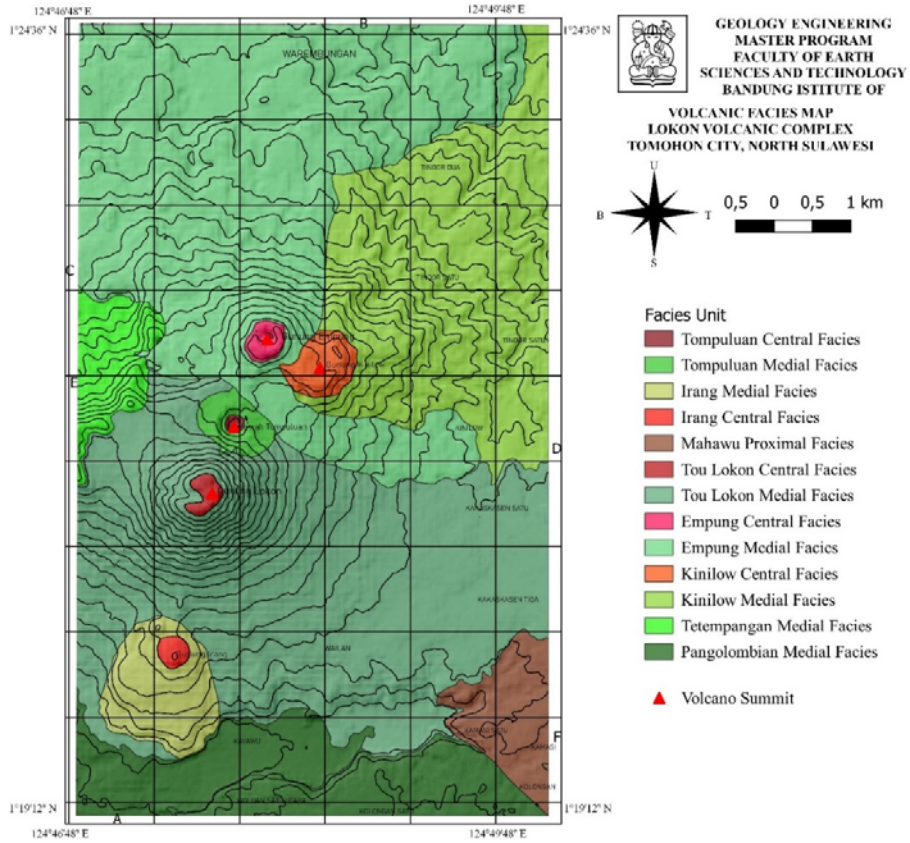

Figure 11 Volcano Facies Map of Lokon Volcanic Complex based on Bogie & Mackenzie (1998) volcanic facies division.

5. CONCLUSION

Based on the results obtained, it can be concluded that:

1. There are 9 Geomorphological domains that explain the relative age and limits of volcanic products in the area of Mount Lokon and its surroundings. Domain is based on Fornaciai *et al.* (2010) using DEM data.
2. Field observations succeeded in dividing volcanic rock units into 18 rock units, dominated by lapilli pyroclastic deposits and andesite to basalt lava flows.
3. Volcano facies in the area of Mount Lokon and its surroundings are the Tatawiran Volcano System, the Kinilow Volcano System, the Empung Volcano System, the Lokon Volcano System, the Irang Parasitary Volcano System, and the Tompulua Parasiter Volcano System.

REFERENCE

Bogie, I. dan Mackenzie, K.M., (1998): *The application of a volcanic facies models to an andesitic stratovolcano hosted geothermal system at Wayang Windu, Java, Indonesia*, *Prosiding 20th NZ Geothermal Workshop*, 265-276.

Fornaciai, A., Bisson, M., Landi, P., Mazzarini, F. dan Pareschi, M. T. (2010): *A LiDAR survey of Stromboli volcano (Italy): Digital elevation model-based geomorphology and intensity analysis*, International Journal of Remote Sensing, **31,** 3177-3194.

Hamilton, W., (1979): *Tectonics of The Indonesia Region,* U.S Geol. Surv., Prof. Paper.

Ikatan Ahli Geologi Indonesia, (1996): *Sandi Stratigrafi Indonesia*.

Ratman, N., (1976): *Geological map of Tolitoli quadrangle, north Sulawesi (1:250.000). Geological survey of Indonesia (GSI), Bandung* dalam B. Priadi, O. H. Ling, E. A.

BULLETIN OF GEOLOGY, VOL. 7, NO. 2, 2023
DOI: 10.5614/bull.geol.2023.7.2.2.

Subroto dan A. S. Subandrio (1995); Studi geokimia unsur utama produk magmatik di Sulawesi Utara, Institut Teknologi Bandung.

Sukamto, R., (1973): Peta geologi tinjau daerah Palu, Sulawesi Tengah, skala 1:250.000. *Direktorat Geologi,* Bandung.

Sukamto, R., (1975): The structure of Sulawesi in the light of plate tectonics. *Proceeding of Regional Convention on the Geology and Mineral Resources of South East Asia,* Jakarta.

Surono dan Hartono, U. (2015): Geologi Sulawesi, LIPI Press, Jakarta.