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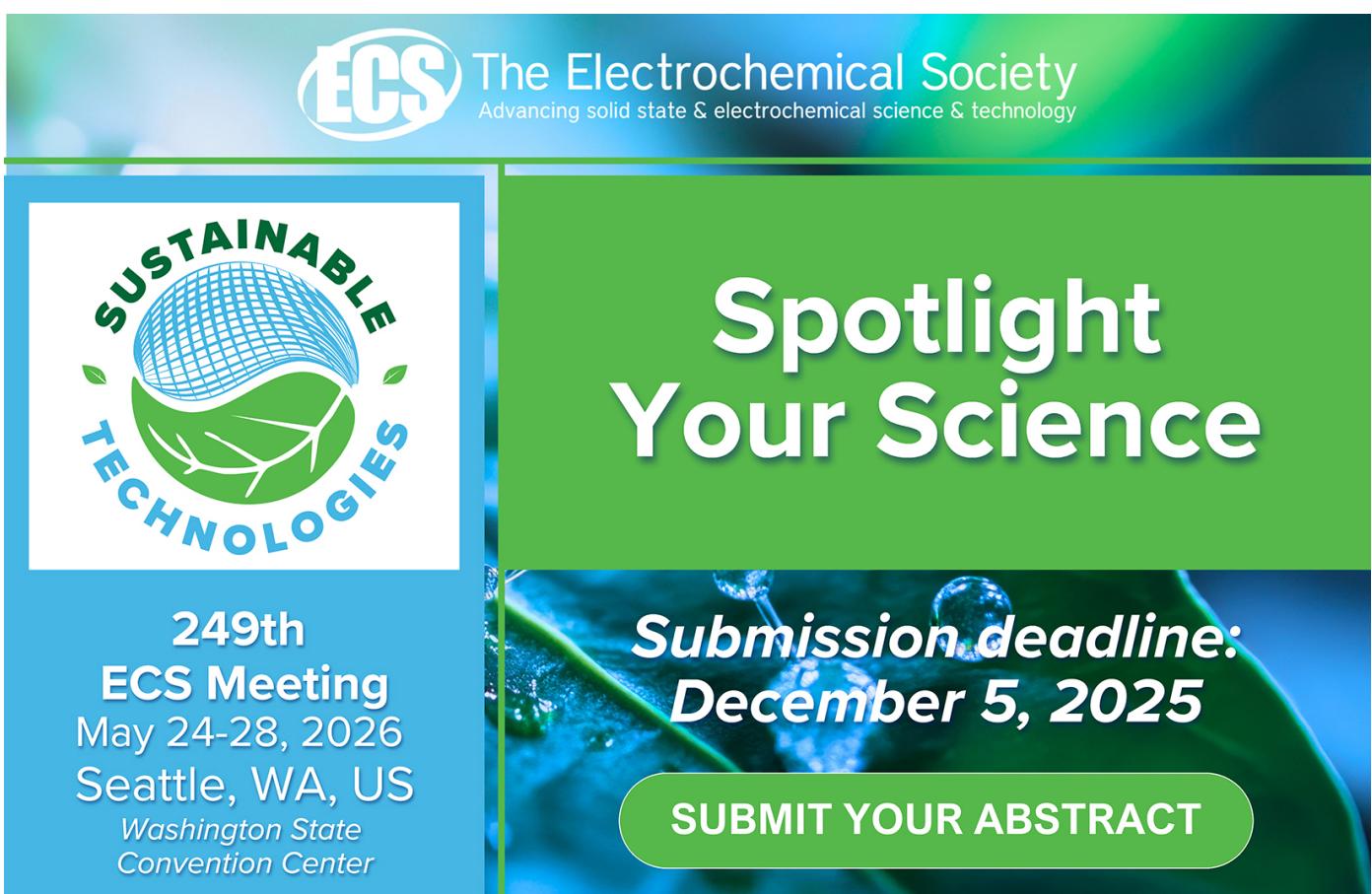
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Geochemical Characteristics of Volcanic Rocks from Mt. Masurai's Caldera, Jambi, Indonesia

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Abstract. Mt. Masurai is one of the volcanoes in Jambi, Indonesia. However, the literature about Mt. Masurai is quite limited until now. Study of the volcano is important as early detection of natural disasters, such as volcano eruption and earthquake. Through comprehensive research, the eruption period of the volcanoes can be predicted and maximum precaution can be planned to minimize disaster victims. In this work, we reported the studies of geochemical Mt. Masurai's rocks. A total of 120 rock samples were characterized using XRF ARL 9900 for the major elements while the trace and rare earth elements were characterized using ICP-MS. In addition, paleosol and charcoal samples were dated using 14-carbon dating instruments. Based on the results of data analysis, the types of rocks according to geochemical classification are basalt, basaltic-andesite, andesite, dacite, and rhyolite. The rocks spread from south to north of the Mt. Masurai's Caldera. The age of the Mt. Masurai's north rocks is 32,786 calBP while the age of the Mt. Masurai's southern rocks is 21,335 calBP. Mt. Masurai has undergone two eruption periods until now.

Keywords: Mt. Masurai's Caldera, Geochemistry, volcanoes, major elements, trace elements

1. Introduction

Indonesia is one of the countries located in the ring of fire that is very vulnerable to natural disasters such as volcanic eruptions and earthquakes that will happen at any time [1]. As a place that produces most of the volcanic activity and earthquakes, Indonesia is a fascinating place for especially volcanoes study. Understanding more about the volcanoes and being able to accurately predict volcanic eruptions and earthquakes may help eventually save millions of lives.

Geochemical study was conducted in the southern part of Merangin Regency which is a hill highlands area formed by the influence of the appointment by a large Sumatran fault with intensively magmatism activities [2, 3]. The reason for choosing the study area is because this area is built on the form of the oldest rock formations (Permian) to the youngest (Holocene) so that it can be an object for various dating techniques [2, 3]. In addition, based on the reference side, this area is less mentioned in research and scientific publications.

The research was conducted mainly on rock units Qv, Qhv and Qtv listed on the geological map (1: 250,000 scale) of the Sorolangun and the Sungai Penuh sheet [2, 3]. The base rocks included in the Asai formation. The research area reaches 30 x 50 km² and covers four sub-districts in Merangin Regency, namely Muara Siau, Lembah Masurai, Jangkat and Sungai Tenang.

2. Regional Geology

The study area is a hill highland in the area around the east-west width of about 30 km while the southern part is limited by the Barisan hills (The Bukit Barisan) line and the main fault of Sumatra (Semangko fault). Geologically this region is composed of units of quartz precipitate: Qv, Qhv, and Qtv as described on the geological map of the Sorolangun sheet [2] and the Sungai Penuh sheet [3]. In the central part of the region there are two cone volcanoes namely Mt. Masurai and smaller cones in the east of Mt. Tungkat. The area of Mt. Masurai is covered by Holocene rock units namely tuff, lava, volcanic-breccia, breccia-tuff, and lava while Mt. Tungkat covered by the distribution of Qv rock units in the form of breccia-volcano, lava, and tuff. The Qtv lithologies are so widespread, especially in the southern region in direct contact with the Bukit Barisan, is a product of rhyoandesitic volcano which are: tuffs, volcanic-breccia, rhyodacitic lava, obsidian, breccia-tuff, and lava. These Qtv lithologies have pinned some rock intrusion in the Pliocene. One of them is a Langkup granodiorite rock samples that can be found in the Pulo Tengah and Kotorawang Village which is the intrusion that occurred in the Sumatra fault zone at the end of the Neogene period. The right (east) and north is directly bordered by the Jurassic Asai formation composed of igneous rock, slate rocks, phyllite, and the silicified silt rocks.

Furthermore, the studied area is strongly influenced by the presence of several active fault of Sumatra namely Dikit fault, Seblat fault and which cut the two faults namely Pandan fault. Dikit and Seblat fault form a compressive 'ramp' in the Bukit Gedang area.

Many of the faults are parallel to the great fault of Sumatra. The Qv, Qhv units appear to be the youngest unit of rock in the study area, however, there is no mention in the currently available geological map.

3. Sample Selection and Analytical Techniques

Lava flows, lithic, tuff, pumice-fall deposits and ignimbrites from Mt. Masurai have been sampled for geochemical analysis. In addition, some palaeosol and charcoal samples have also been collected for ¹⁴C dating analysis. All laboratory tests on rock samples were carried out following procedures established in national and international standards [4]. A total of 120 rock samples have been collected from field survey activities. Major element compositions were determined by X-Ray Fluorescence (XRF) ARL 9900 while the trace elements and rare earth elements were determined by Inductively Coupled Plasma–Mass Spectrometry (ICP-MS) Thermo IcapQ at the Center for Geological Survey Laboratory.

Prior to geochemical analysis using either XRF or ICP-MS, the rock samples were first cleaned and cut into small pieces using the Crusher. Contaminant materials such as amygdales and rock veins are separated. The rock sample fragments were rinsed with clean water and dried before being ground into a fine powder of ± 200 mesh. The finely powdered rock samples have ready to be analyzed at the Central for Geological Survey Laboratory using XRF ARL 9900 and ICP-MS Thermo Icap Q. The measurement data using either XRF or ICP-MS is validated by using Certified Reference Materials (CRM) is further processed using petrograph and Igpet software.

4. Results and Discussions

4.1. Mt. Masurai's Caldera

Mt. Masurai is located in the Merangin Regency, Jambi province of the island of Sumatra in western Indonesia, within the Barisan Mountains. The Mt. Masurai's coordinate is at $02^{\circ} 30' 09.19''$ N and $101^{\circ} 51' 28.60''$ E, with elevation of about 2915m above sea level. At its summit, there are two crater lakes namely Kumbang Lake and Merbuk Lake which has a diameter of about 500 m and also another eruption hole (K1) at coordinates $02^{\circ} 27'47.30''$ N and $101^{\circ} 53'36.76''$ E, with elevation 2060 m above sea level shown in figure 1. The peak morphology of Mt.Masurai appears to be decapitated and forms a caldera morphology with a diameter of about 7km. The caldera is on the left (west) has a wall which is the

highest peak Mt.Masurai and on the right (east) has a residual circular caldera wall with the rim elevations between 2000 m to about 2250 m, leaning toward the northwest. The estimated subsidence of altitude difference between the caldera rim and the caldera area is 200 m, which means there is a subsidence volume of, at least, 8 km³. This quantity is equivalent to the volume subsidence of the caldera Batur II [5].

Based on satellite imagery it appears that Mt. Masurai's caldera morphology has an openings in both directions, namely in the northwest and southeast direction. Both directions appear to be covered by post-caldera products that culminate in forming the Kumbang Lake and Merbuk Lake. On the caldera's area appears the remains of parasitic eruption holes one of which is referred to as the Blue Lake. Although the size is relatively small with a diameter of about 80 m, its blue color makes this lake is widely known to the public. The Blue Lake lies in the coordinates of 02° 30' 29.30 "N and 101° 53' 56.90" E which is located in the caldera's courtyard at a distance around 250 m from the caldera alley. The blue color in the lake appearance is most likely due to the process of light filtering by the compounds contained in the lake bottom mud.

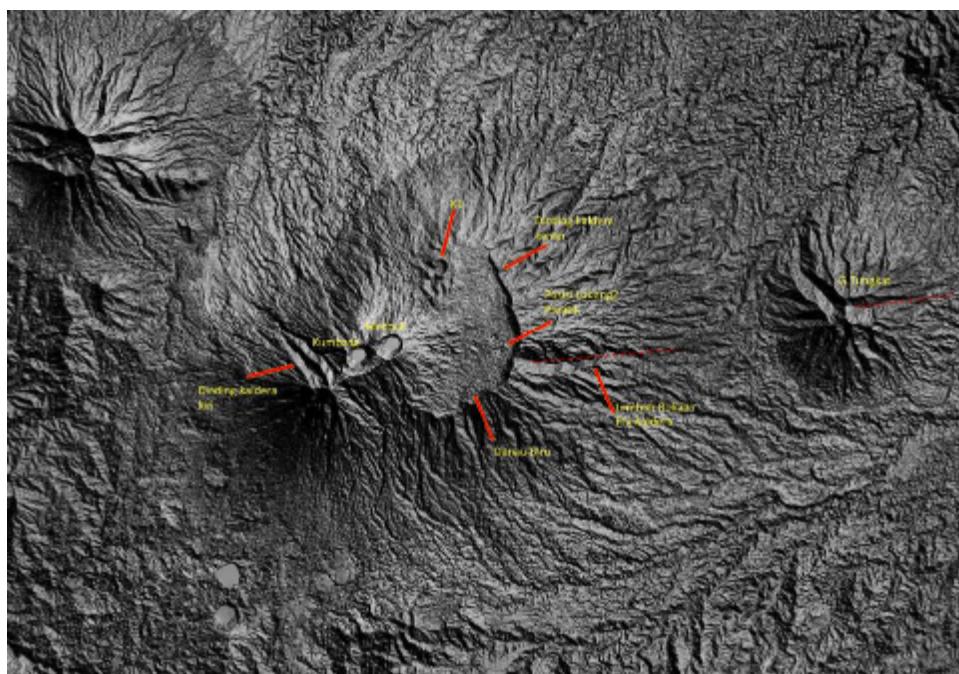


Figure 1.The physical appearance of the caldera wall still appears in the field. Hypotheses can be built units of deposits of pumice stone which is the result of the process of making the Mt.Masurai's caldera. The small cone on the right is Mt.Tungkat.

Figure 2 shows the layering of pumice becomes an indication that before the caldera formation by eruption, the activity of Mt.Masurai begins with volcanic and Plinian eruptions that scatter the stone. By the Nilo River flow, these pumice fragments in several layers are precipitated by a fluvial precipitation process. The presence of a fluvial process prior to precipitation of the ignimbrite proves that the Nilo River valley has existed prior to the occurrence of that precipitation and suggests that the overriding groove of ignimbrite follows the Nilo River Valley towards the north and the valley of the Siau Valley in the northeast. The presence of the pre-ignimbrite Nilo River Valley is also indicated by the overlying deposition pathway of Lubuk Pisang where on the right side of the left, the sediment is limited by the highland of Asai Formation.



Figure 2.The ignimbrite's outcrops in the Nilo River area which already has several series of pyroclastic deposits

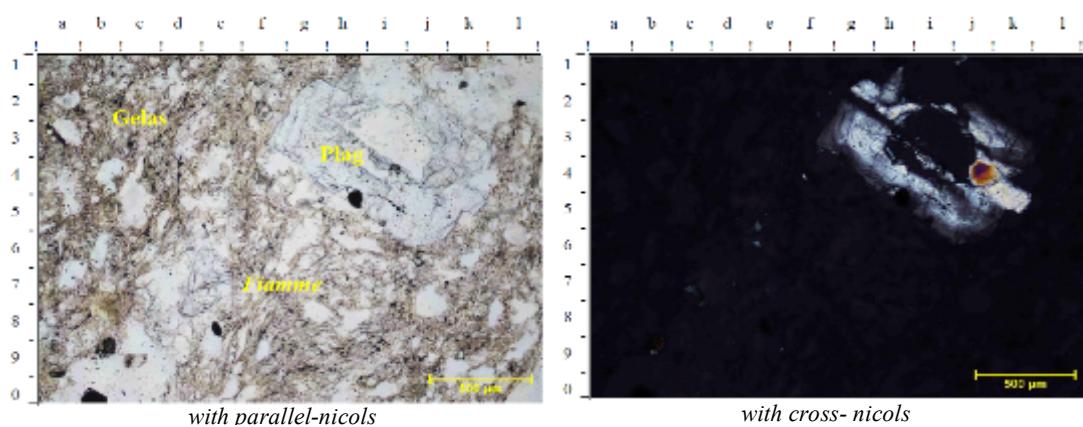


Figure 3.Microphotographs showing textures and mineral assemblages of welded vitric-tuff (ignimbrite)

The ignimbrite deposits are scattered in the northern part of Mt.Masurai, where the ignimbrite's outcrop can be found in several locations such as Nilo River, Sisin River, Kotorami, Tekurung Badak, Lubuk Beringin, and Lubuk Birah. From these locations, the outcrops of the Nilo River and Lubuk Birah River are important locations because they are found in thick sequences of ignimbrite and associated with pyroclastic fall deposits.

Figure 2 show the outcrop of Nilo River Valley contains a complete series of pyroclastic precipitate processes so that detailed stratigraphic measurements from the bottom of the basin up to the top of the cliff are observed. In general, there are several series of pyroclastic deposits which are on the bottom is a series of pyroclastic flows forming a white-colored ignimbrite looks consolidated about 4 m. Then, on the top of which deposited pyroclastic fall of lapillus volcano and tuff fine-rough with a total thickness of 25 cm. Hereinafter, the ignimbrite-pumice series not consolidated as thick as 70 cm, recurrent pyroclastic fall deposits of 26 cm thick lapillus-tuff rugged volcano, continued on top of the form described ignimbrite with the composition of pumice and lithic as thick as 30 m in the middle form the structure of 'fiamme', and in the top is the series of non-welded ignimbrite-pumice-lithic rocks. The composition of the ignimbrites is dominated by fragments of pumice, lithic, quartz mineral, hornblende with a coarse volcanic ash matrix.

Pyroclastic rocks in the form of a flow with a fragment of plagioclase (0.8 - 0.2 mm). Figure 3 shows the structure of zoning and pyroxene (0.2 - 0.1 mm) with a mass basis of juvenile glasses (0.6 to 0.3 mm) is having to weld and volcanic ash (<0.004 mm), with angular-sub angular grain shape, poorly sorted, opened packing (inter fragment). These rocks are formed due to the flow of material volcanic eruption on the mechanism of pyroclastic density current. In the process of juvenile magma flow material in the form of solid obsidian glass is still hot condition and changes shape (flattened) so that the rocks undergo the welding process.

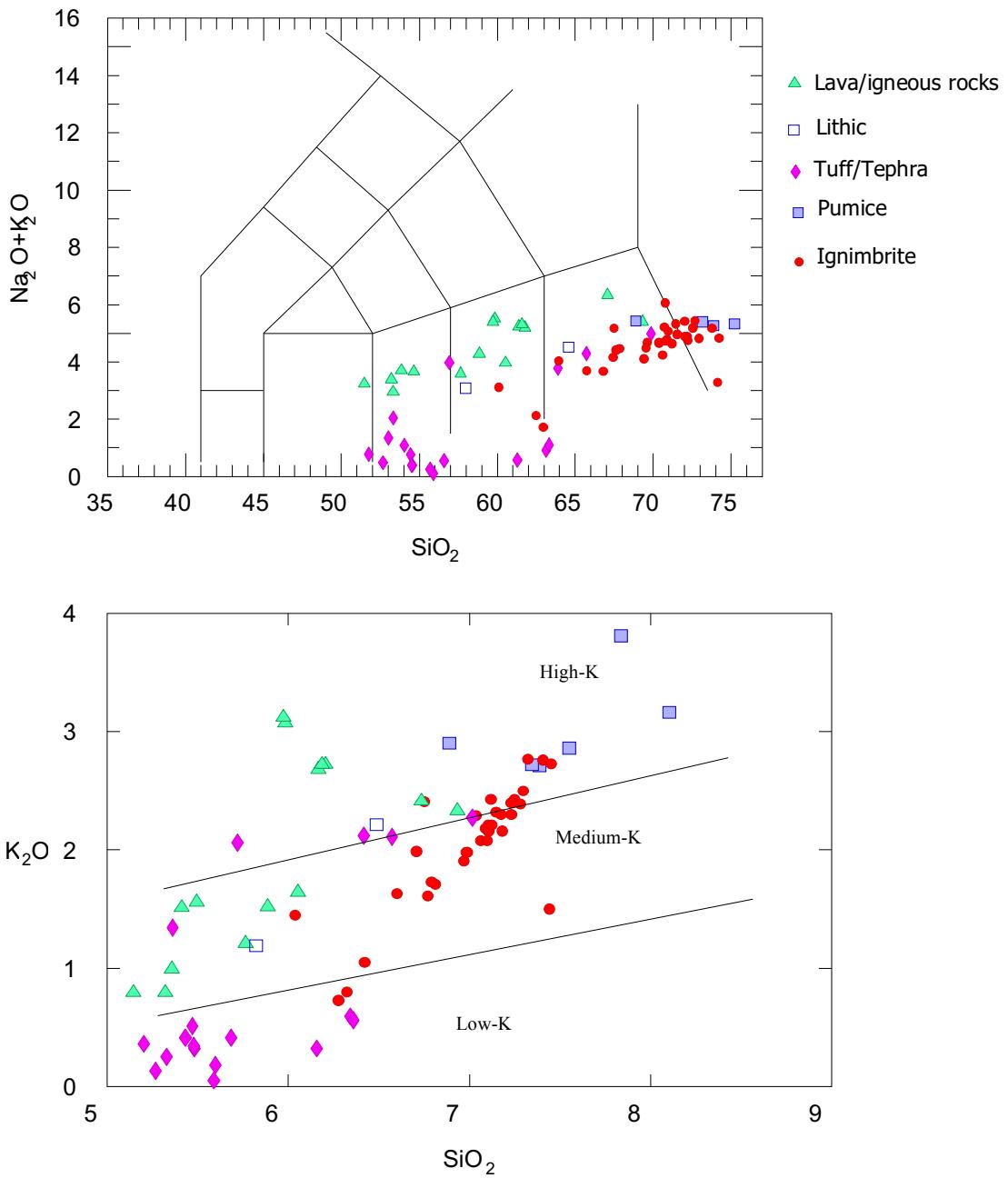
4.2. Geochemistry of Mt. Masurai's Caldera

Figure 4 and figure 5 show the results of the major and trace element analysis of the ignimbrites, tuff/tephra, lava and pumice of the Mt.Masurai area (102 samples) respectively. Meanwhile, the results of 14-carbon dating analysis of the charcoal and paleosol samples are 32,786 calBP and 21,335 calBP. It can be interpreted that there may have been two eruption period. However, this needs to be reinforced with more comprehensive data. Therefore, there are several samples being analyzed with a fission track to determine its age.

4.2.1. Major Elements

Figure 4 shows geochemical analysis results of major elements reflected in the TAS diagram. In generally, igneous rocks and ignimbrite's group have a variety of SiO₂ (51 – 78%) are assumed to represent the tendency of SiO₂ content (45 – 70%). The TAS diagram shows the presence of two groups of magma properties namely rhyodacitic and andesite-basalt. Furthermore, the magma affinity based on the K₂O vs. SiO₂ diagram, are generally in the igneous rocks and the ignimbrite's group is Calc-Alkaline series and High-K Calc-Alkaline series.

Meanwhile, some rock samples (Tuff/Tephra) have a Tholeiitic tendency. Based on the results of all analyzed Tuff/Tephra samples have SiO₂ contents in the range of 52 – 70 %, MgO (0.1 – 1.8 %), FeO (2 – 9%), TiO₂ (0.8 – 12 %), and Al₂O₃ successively high (15 – 42%) while K₂O range from 0.1 – 2.3%. This is probably associated with post-YTT (Youngest Toba Tuff) volcanics which have a SiO₂ content range of 52 – 76% as proposed by Chesner,C.A. [6]. Alternatively there is a mixture of eruptions with Mt.Tungkat which has basaltic magma characteristics. To support this interpretation further research is needed.

Figure 4.The TAS diagram (above) and K_2O vs. SiO_2 diagram (below)

Based on the results of all analyzed samples showed that igneous rocks of Mt. Masurai belong to the medium Calc-Alkaline to High Calc-Alkaline series [7], and have SiO_2 contents in the range of 51 – 69 %, MgO (1 – 6 %), FeO (2 – 9%), TiO_2 (0.3 – 1 %), and Al_2O_3 successively high (13 – 18%) while K_2O range from 0.8 – 3% with a FeO^*/MgO ratio of about 1.48% to 4.50 %. The data is a characteristic of volcanic rocks formed in island arc environment, as proposed by Miyashiro [8].

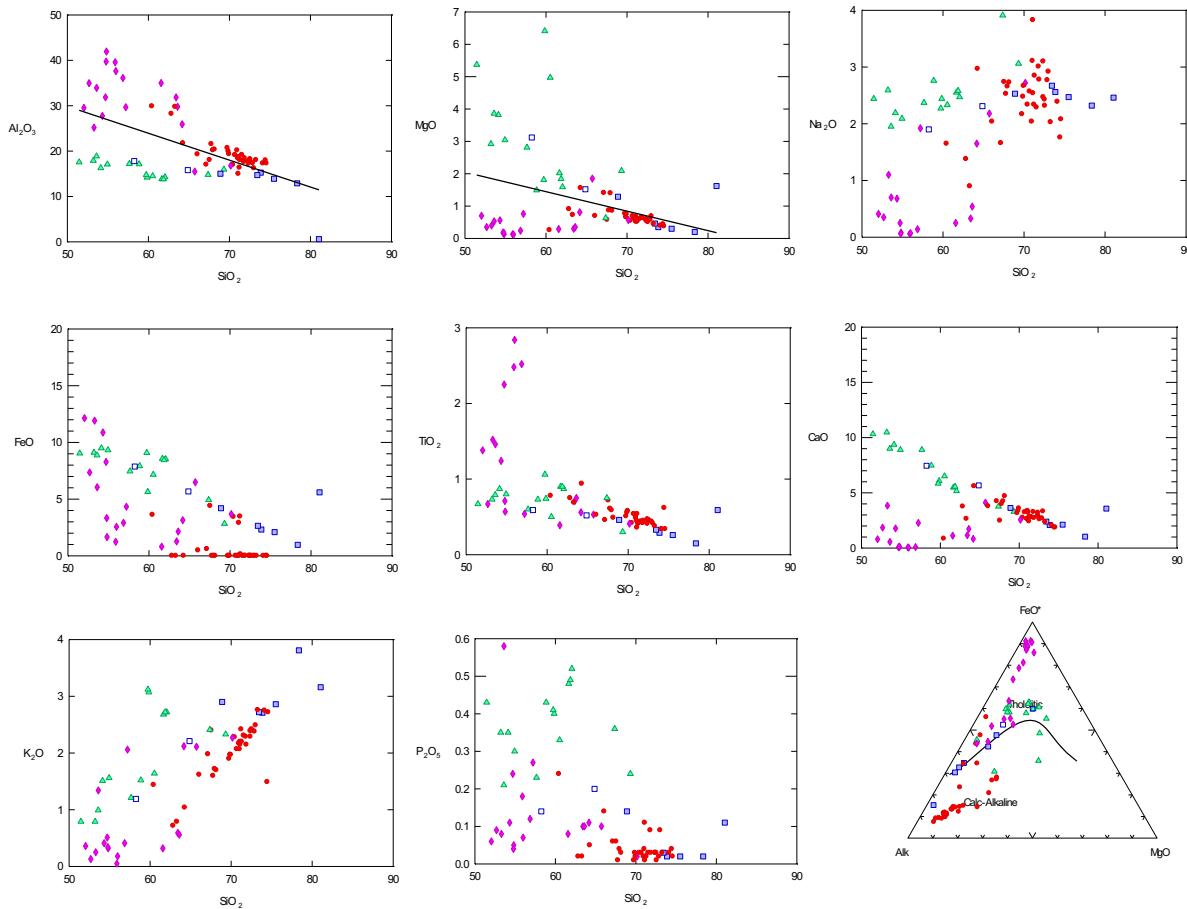


Figure 5.The Harker and AFM diagram of whole-rock samples

Based on the Harker variation diagrams, Na_2O and K_2O are positively correlated with SiO_2 shown in Figure 5, indicating the normal crystallization process of feldspar. This shows the level of normal differentiation, namely the older age rocks are relatively poorer than the silica of younger rocks. Although K_2O behavior shows a clear positive correlation, it is the distribution that is somewhat away from the trend in some samples may occur due to the influence of the crust. This is commonly in the subduction zone setting [9]. Negative correlations are generally shown in the relationship of CaO , MgO , Al_2O_3 , Fe_2O_3 , to SiO_2 . This is consistent with ferromagnesian minerals and plagioclase fractionation of basaltic magma origin [9]. Correlations on the oxides TiO_2 , and P_2O_5 tend to spread.

4.2.2. Trace Elements

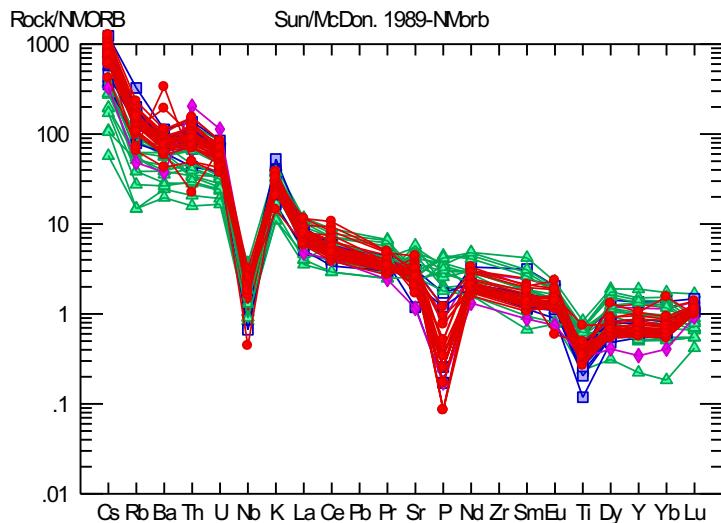


Figure 6. The Spider diagram of trace elements LILE and HFSE rock samples in research areas with normalization of NMORB according to Sun/McDon-NMORB (1989).

Based on the plot spider diagram with N-MORB normalization shown in Figure 6, it can see the enlargement trend of LILE (Large Ion Lithophile Elements) that is Rb, K, Ba, Sr which is also an incompatible element while HFSE (High Field Strength Elements) such as Nb, Ti, P, and Y tend to below except the enriched Th element. The LILE enrichment is associated with basaltic magma metasomatism by the fluid from the plunging plate while the reduction of HFSE is associated with high degree of partial melting [10]. This pattern is in accordance with the expected volcanic rocks of subduction zone products [11, 12].

5. Conclusion

Based on the field data and geochemical analysis results, it can be interpreted that Mt.Masurai has occurred two major eruptions. The first major eruption occurred in 32,786 calBP formed a caldera's morphology with an average diameter of 8 km and the second major eruption occurred at 21,335 calBP. The magma series is generally composed of two types of magma that are andesitic-basaltic and rhyodacitic, which produce the first large eruption to form the caldera, which are included in the Calc-Alkaline and Tholeiitic series as a result of mixing eruption product from other volcanoes. The existence of two types of magma is the result of the magma differentiation process in volcanic arc tectonic environment. The temporary Interpretation of the subsurface, it appears that there are two main pockets of magma in which at the bottom is a basaltic-andesitic magma chamber and rhyodacitic magma chamber is shallower. In the primary magma differentiation, the fluid supply is the main magma mantle partial melting of oceanic crust (NMORB) in the subduction process resulting volcanic arc of Sumatra. Furthermore, magma undergoes differentiation by melting of side rocks derived from sedimentary rocks (Continental Margin) producing rhyodacitic magma types. Further research needs to be done in order to produce more representative, valid, and to produce a comprehensive conclusion.

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