PETROLOGY OF LAVA FROM THE MANINJAU LAKE, WEST SUMATERA

*Bhakti H. Harahap and Hamdan Z. Abidin *)*

ABSTRACT

Andesitic lavas and rhyolitic tuffs are the main products of the Maninjau Lake during Pleistocene. The lava is distributed up to radius of 20 km, whiles the tuff 100 km that suggests a high explosive volcanic. The lava is exposed beautifully along the road from Bukit Tinggi to Lubuk Basung mapped as **Qamj** on the 1:250 000 geologic map of Padang Quadrangle. The lava is having sheeting joint in some parts, dark gray, highly porphyritic in texture with phenocrysts of plagioclase, clino-pyroxene, ortho-pyroxene and opaques. Quartz phenocryst occurs in rhyolite lavas that are rarely found in the area. Xenoliths of diorite are occurred in some andesite. The lavas have narrow range in silica composition ranging from 54-60 wt % and rarely up to 69 wt%. K_2O versus SiO_2 relationship shows that analyzed samples belong to calc-alkaline series which are mainly of high-K. While the trace element of the rocks is summarized on the spider diagram, here their patterns strongly resemble the typical of arc lavas with enrichment in large ion lithophile elements (LILE) and light rare earth elements (LREE) relative to high field strength elements (HFSE) and heavy REE (HREE). More over, these patterns show an Nb resembling the arc type magma commonly resulted from subduction, whether in island arc or active continental margin. The geochemical characteristic of the lava from Maninjau Lake is a lower concentration of Ba, Sr and La than other active continental margin like the Andes volcanic rocks. Like many other subducted related rocks, the andesite characterize a very evolved magma, where they have low MgO concentrations (3 wt%) with Mg# 30-53. According to the plate tectonic model, Sumatera is on the continental side to subduction process since Eocene until the present. The presence of subducted magma character in Maninjau Lake area was argued to have been accounted during the eastward subduction of the India-Australia Oceanic Crust. It seems also that Sumatra Fault Zone is a very important agent to conduit magma onto the surface in the Barisan Ranges including the lava resulted from Maninjau Lake.

Keywords : petrology, andesitic lava, rhyolitic tuff, Maninjau, Pleistocene

SARI

Danau Maninjau yang aktif pada Plistosen telah mengeluarkan lava andesit dan tufa riolit yang masing-masing tersebar sampai radius 20 km dan 100 km, sehingga dikategorikan sebagai vulkanisme yang sangat explosif. Lava yang tersingkap secara baik di sepanjang jalan Bukit Tinggi - Lubuk Basung, dipetakan sebagai **Qamj** di dalam peta Lembar Padang skala 1:250 000. Lava ini berstruktur kekar lembar di beberapa tempat, berwarna abu-abu gelap, bertekstur porifiritik kuat dengan fenokris plagioklas, klinopiroksen, dan ortopiroksen. Fenokris kuarsa terdapat pada riolit yang jarang ditemukan. *Xenolith* diorit terdapat pada beberapa percontoh batuan yang berkomposisi andesit. Lava Maninjau ini mempunyai kandungan silika yang kisarannya dari 54 sampai 60 % berat dan jarang yang mempunyai komposisi silika mencapai 69% berat. Dalam diagram SiO_2 lawan K_2O semua percontoh batuan terplot pada lapangan seri kalk-alkali yang kebanyakan mempunyai K-tinggi. Sementara unsur-unsur minor yang dirajah dalam diagram laba-laba memperlihatkan pola grafik menyerupai lava yang terjadi pada busur gunung api, yaitu berupa pengayaan *LILE* (*Large Ion Lithophile Elements*) dan *LREE* (*Light Rare Earth Elements*) relatif terhadap HFSE (*High Field Strength Elements*) dan HREE (*heavy REE*). Demikian juga pola grafik pada unsur Nb yang menukik secara tajam mencirikan magma hasil penunjaman, baik itu di busur gunung api maupun pada tepian benua aktif. Sifat khas kimiawi batuan ini mempunyai kandungan unsur Rb, Sr, dan La yang rendah dibandingkan dengan tepian benua aktif lainnya seperti batuan gunung api Andean. Seperti halnya pada batuan yang berkaitan dengan subdaksi, batuan andesit mempunyai ciri magma yang terevolusi, dengan kandungan MgO rata-rata sebesar 3 % berat dan nilai Mg# 30-53. Menurut teori Tektonik Lempeng, daerah Sumatera langsung berhubungan dengan subdaksi sejak zaman Eocene sampai sekarang. Oleh karena itu adanya ciri kimiawi magma subdaksi di daerah Danau Maninjau boleh jadi berkaitan dengan subdaksi Kerak Samudera India-Australia ke arah timur. Sesar Sumatera juga merupakan pemicu keluarnya magma di sepanjang Bukit Barisan termasuk hasil gunung api Danau Maninjau.

Kata kunci : petrologi, lava andesit, tuf riolit, Maninjau, Plistosen

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INTRODUCTION

Lake Maninjau is an elliptical cauldron, 16 km long and 8.5 km wide and has an area of 96 km square (Figure 1). The eastern border of this volcanotectonic depression is formed by rocks of the basement complex (granodiorite, diabase, phyllitic schist, and limestone). Historically the Maninjau Lake was one of an active volcano as in Sumatera that was as old as the famous Toba Lake in North Sumatera. Maninjau had produced a great amount of lava flow and tuff (ignimbrite) as piedmont, the former distributed surrounding the lake itself with radius of 20 km, while the latter up to 100 km covering a wide area including Solok, Lubuk Sikaping, and Padangsidempuan - Sibolga Quadrangles. The lava is beautifully exposed on the road between Bukit Tinggi and Lubuk Basung especially at the 44 winding road (*kelok 44*), consisting mainly of massive and dense lava flow of andesitic composition. The Pleistocene lavas discussed in this paper are mapped as lava andesite (Qamj) (Kastowo *et al.*, 1996). They were informally named **Andesite of Danau Maninjau Caldera** in the Stratigraphic Lexicon of Indonesia (Harahap *et al.*, 2003). They occurred in a subaerial environment. The lava samples were collected from outcrop at location of GPS (Global Positioning System) as shown on Table 1, when the fieldwork was conducted on June 2005. The geological traverses were running along the road from Bukit Tinggi town toward southwest and turn around to Maninjau Lake and then to Lubuk Basung town. Tens samples have been collected sporadically along the road near the Lake of Maninjau and thirteen samples have been further analyzed in the GeolLabs of the Centre of Geological Survey in Bandung, including major, trace, and rare-earth elements. This area of study covers the central part of the Padang Quadrangle (Kastowo *et al.*, 1996).

The study of volcanic rocks in Maninjau was part of the field research programme on *Mineral Bijih Busur Magmatik* (*MBBm*) that was financially supported by Geological Research Development Centre (now Centre of Geological Survey) project. The first author was appointed as a project coordinator which also responsible for the petrological aspect.

Maninjau Lake region is known as a tourist area located approximately 60 km northwest of Padang, a capital province of West Sumatera, which can be reached easily because a highway passes through this region. The landscape is dominated by volcanic hills with vertical cliff. Previous studies on magmatic rocks resulted from Maninjau Crater were reported by Kastowo *et al.* (1996). The volcanic products of the crater are mapped into two units of Andesite of Danau Maninjau Caldera (**Qamj**) and Pumiceous tuff and andesite (basalt) (**Qpt**). This Pumiceous tuff on the Lubuk Sikaping Quadrangle has been studied by Rock *et al*. (1983), and reported that the age of the tuff is 2.8 m.y. They further reported that the Neogene's volcanism in Sumatera have a wide spectrum of magma composition ranging from basalt through to rhyolite. Where, the volcanism involves large volumes of felsic eruptives. This paper presents new geochemical data of Pliocene-Pleistocene volcanic rocks obtained on June 2005 in the particular area of Maninjau Lake and discusses the geochemistry and other important petrological aspect and relates them to the plate tectonic, a model for its magmatic petrogenesis.

REGIONAL TECTONIC FRAMEWORK

Sumatera is one of ideal examples among the other places like America, Japan, Alaska, New Zealand, and the Aegean in which the overriding plate is a continental one (see Figure 7.1. in Wilson, 1989). A volcanic arc develops upon an uplifted surface of Paleozoic rocks along the Indian Plate margin of Sumatera by the Permian volcanic activity which has been essentially continuous to the present day. Like the continental margin of America, granite occurs in many places in Sumatera which is probably a root of the volcanic.

Table 1. Sample Location Based on Global Positioning System (GPS)

Sample No.	Name of rocks	GPS measurement/location	
05PDG53A	Andesite	N0°18′064″	E100°14′805″
05PDG53B	Andesite	N0°18′064″	E100°14′805″
05PDG54A	Andesite	N0°17′995″	E100°14′431″
05PDG55A	Andesite	N0°18′043″	E100°14′134″
05PDG55B	Andesite	N0°18′043″	E100°14′134″
05PDG56A	Andesite	N0°18′008″	E100°13′993″
05PDG57A	Volcanic pyroclastic	N0°17′888″	E100°13′636″
05PDG58A	Andesite	N0°14′947″	E100°11′444″
05PDG59A	Andesite	N0°17′085″	E100°09′343″
05PDG60A	Andesite	N0°17′921″	E100°08′561″
05PDG61A	Andesite	N0°18′138″	E100°07′896″
05PDG62A	Andesite	N0°18′520″	E100°07′173″
05PDG63A	Andesite	N0°18′924″	E100°06′566″

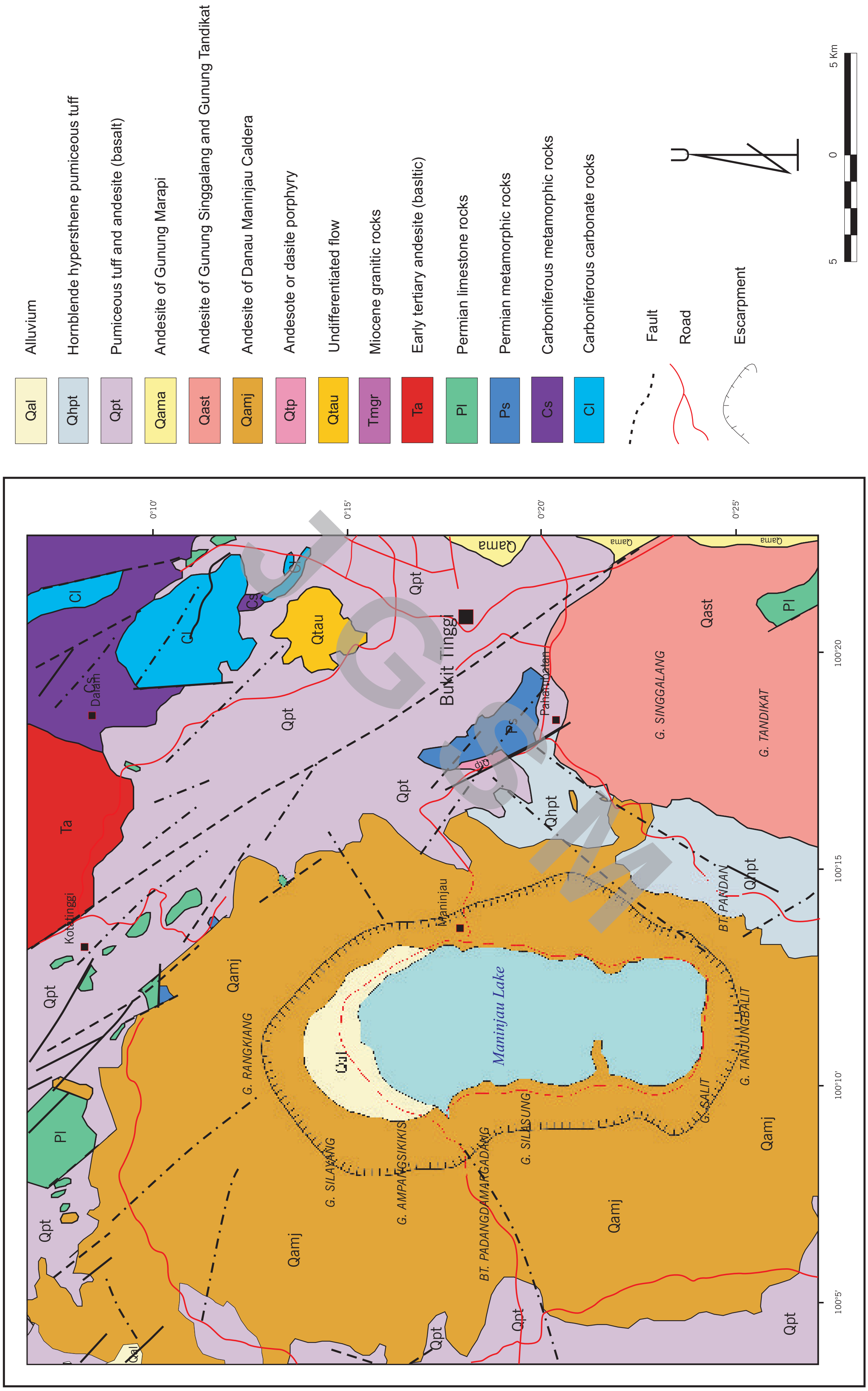

Figure 1. Geologic Map of Maninjau Lake West Sumatera (after : Kastowo *et al*., 1996).

At the present time Sumatera represents part of Sundaland, a southern part of the Eurasia Continental Plate (Figure 2). Oceanic crust flooring the Indian Ocean is being consumed at the western margin of this plate. Sumatera is dominated by a volcanic arc resulting from magma generation along the underlying Benioff Zone. The incoming oceanic crust is approaching the trench obliquely from the south. Resulting stresses are periodically relieved by dextral movements of faults approximately parallel to the plate margin.

From the Eocene onwards, Sumatera was the site of a periodically active volcanic arc and widespread sedimentation. The continued oblique approach and subduction of the India-Australia Plate under the continental Sundaland resulted in dextral strike-slip displacement, most marked in the western part of Sumatera. Tectonic uplift during Early Miocene was accompanied by minor granite (**Miocene Granitic Rock, Tmgr**). The Sunda Subduction Complex continued to migrate oceanward during Early Miocene to Late Miocene times, the trench axis lying slightly west of Nias Island (Karig *et al*., 1980).

Uplift of the Barisan at post Middle Miocene Tectonism. As in Late Oligocene to Early Miocene, volcanic activities culminated towards the end of Early Miocene to Late Miocene cycle and herald the onset of regional uplift and marine regression. Uplift began in the late Middle Miocene, probably climaxed at the Mio-Pliocene boundary and has continued irregularly until the present. Although the main axis of the uplift was in the Barisan Mountains, parts of the continental shelf to the west of Sumatera temporarily emerged in the later Miocene (Karig *et al*., 1980, Mertosono and Nayoan, 1974). Deformation of the older Tertiary was initially restricted to shearing and folding between stable fault blocks. Along these faults, which seem to be controlled by a complex system of pre-Tertiary anastomising shears that dissect Sumatera, both vertical and dextral movement occurred.

Pleistocene Tectonism. The modern geography of Sumatera took shape following uplift in the early Pleistocene. Although dextral fault motion continued, the most important movement, which resulted from a brief period of rapid uplift of the geanticline were along the powerful lines of normal faults and monoclinal structures that define the eastern and western margins of the Barisan Ranges. These vertical movements are attributed to thermal forming above large volumes of magma rising from the underlying Benioff Zone (Karig *et al*., 1978, Hamilton, 1979) and it is clear there was a marked increase in the level of volcanic activity immediately following uplift. The most dramatic manifestation of this is the Toba Tuffs, but similar, less voluminous, tuffs were erupted along fault lines to the south such as the Maninjau tuff and intermediate volcanism continued. The Toba volcano-tectonic depression collapsed following the eruption of the Toba Tuffs (Bemmelen, 1949).

GEOLOGY

The geology around Maninjau Lake (Figure 2) is presented based on 1:250.000 geologic map of Padang Quadrangle (Kastowo *et al*; 1996). The oldest exposed rocks in the area are Carboniferous metamorphic and carbonate rocks, where the former is called Phyllite member of the Kuantan Formation and the latter Limestone member of the Kuantan Formation. These units are unconformably overlain by Permian Metamorphic rocks and Quartzite member of Permian rocks. The Permian metamorphic rocks consist of phyllite, slate hornfelsic and mica greywacke, and the quarzite member with beds of siltstone, greywacke and volcanic rock. The Permian units are conformably overlain by Jurassic limestone and Jurassic sediments of quartzite, shale, siltstone, and slate. These Paleozoic and Mesozoic rocks are in fault contact with Ultrabasic rocks, and intruded by Cretaceous Granite. The whole pre-Tertiary rocks are acting as a basement rock, and unconformably overlain by Tertiary and Quarternary rock units. The oldest Tertiary unit is Early Tertiary andesite that underlies the Sirabungan Mount and mainly made up of breccia. Younger units are Miosen Limestone, Miocene Polymictic Conglomerate, Miocene Sandstone and Oligo-Miocene Volcanics. The old Tertiary rocks are covered by Pliocene to Pleistocene volcanic rocks, which are Undifferentiated flows, Andesite of Gunung Talamau, Pumiceous tuff and andesite, Andesite of Danau Maninjau Caldera, Lithic crystal tuff, Andesite and tuff, Andesite of Gunung Singgalang and Gunung Tandikat, Andesite of Gunung Marapi, and subvolcanic rocks of Andesite or Dasite porphyry and Aphanitic rhyolite.

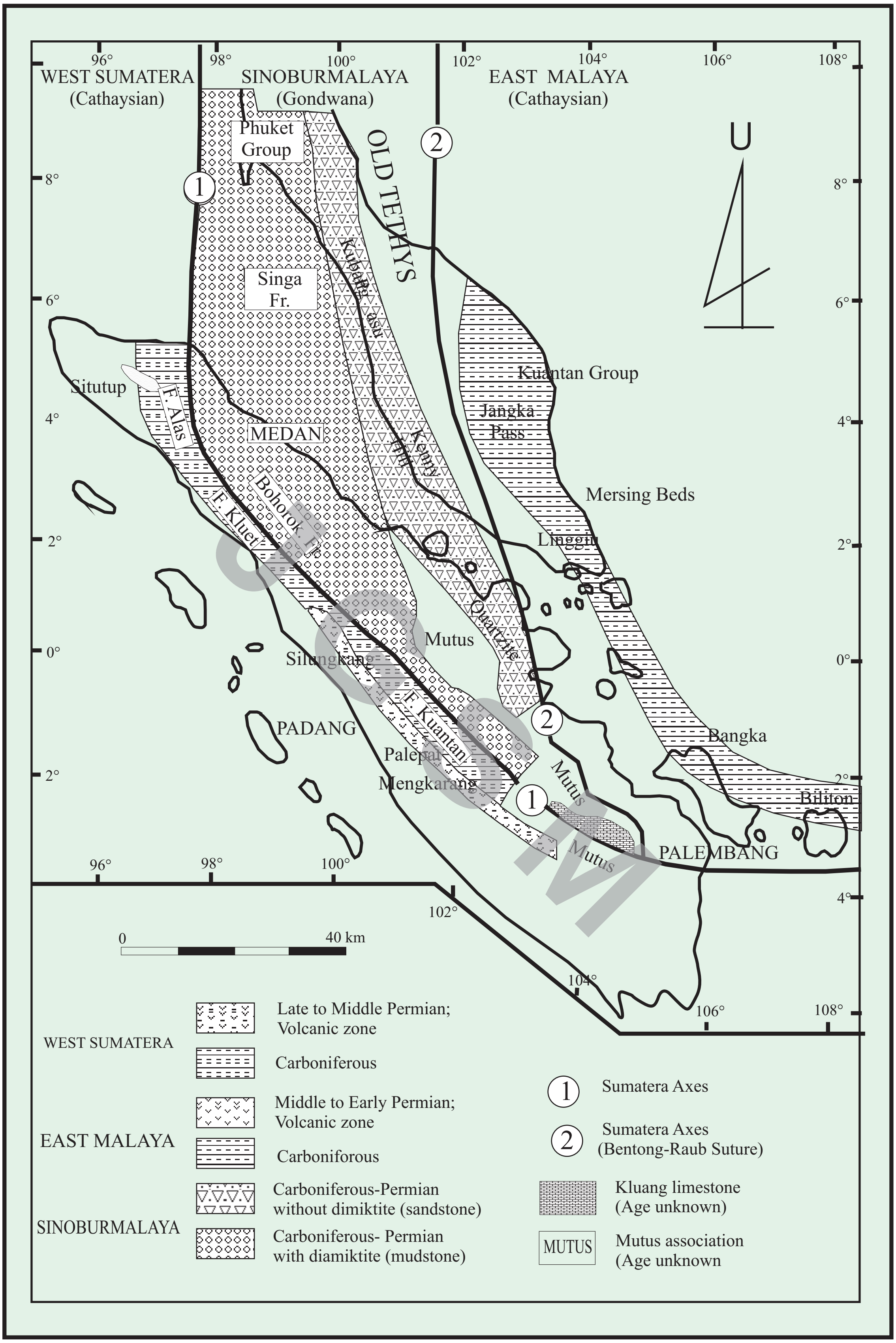

Figure 2. Regional tectonic of Sumatera after Aspden *et al.* (1982).

ANALYTICAL PROCEDURES

Forty samples have been collected along the road near Maninjau Lake. They are generally fresh and relatively easy to collect since the exposures are old road cutting. All of them have been prepared manually for thin sections at the Geol*Lab* of Centre for Geological Survey, Bandung (CGS) and then determined petrographically through optic binocular microscopy at this laboratory by the first author. Selection for further analyses is based on their freshness and rock variation. Geochemical analyses of the rocks including major, trace and rare earth elements were conducted at the Petrology Laboratory, in the Quaternary Laboratory office, a branch of the CGS in Jl. Dr Junjunan Bandung by using *X-Ray Fluorescence* for the major elements, and *Inductively Couple Plasma Spectrometry* (*ICP-MS*) and *Laser Ablation* for the trace and rare earth elements. The analyses were performed by GSI staffs Purnama Sendjaya ST, Ronaldo Irzon ST, and Irfany ST.

PETROLOGY

The Pliocene-Pleistocene volcanic rocks from Maninjau consist of lavas of andesitic and rare rhyolitic composition and tuff. The lavas are generally fresh, medium gray to dark gray, porphyritic in texture with phenocrysts of plagioclase and pyroxene, vesicular and amygdales, in places banding. (Figure 3 and 4). Petrographically, the rocks are generally quite fresh to very fresh and compose of andesite and rhyolite, some andesite contain xenolith of diorite. The andesite are porphyritic, glomeropophyric and ophytic in texture with phenocrysts of plagioclase, clinopyroxene, othopyroxene and rare opaques set in a groundmass of glass and microlith of same minerals as the phenocrysts (see Figure 5 - 8). Olivine occurs in one sample (05PDG 53B) as a phenocryst together with plagioclase, pyroxene, and opaques (Figure 5). The rhyolite is porphyritic in texture with phenocrysts of plagioclase, quartz, clinopyroxene, and orthopyroxene set in a groundmass of glass and microcrystalline of plagioclase and quartz. The plagioclase is generally andesine and labradorite in composition and up to 4 x 2 mm grain size with subhedral form, often strong zoning, some grains with inclusion of pyroxene, plagioclase, and opaque. The clino-pyroxene is subhedral, light greenish gray, zoning, maximum of 3.5 x 1.75 mm in size, some grains with inclusion of plagioclase and some are intergrowth with plagioclase (ophytic textures). Ortho-pyroxene is generally acting as groundmass and rarely up to 2.50 x 1.00 mm in size, high relief, some grains intergrowth with plagioclase, clino-pyroxene and opaque, a few crystals are mantled by clino-pyroxene. The loss of ignition (LOI) of the rocks are low (0.60-3.55) which suggests a quite fresh rocks. In other words, the rocks have not been altered and subjected to metamorphism. Rock types have been classified using SiO_2 versus $Na_2O + K_2O$ variation (*e.g* Cox *et al*., 1979) (Figure 9) where eleven rocks fall within the andesite field and one rock within the rhyolite, and they belong to subalkaline.

Figure 3. Massive andesitic lava as a block standing out on rice field at location 05PDG47.

Figure 4. Outcrop of andesitc lava with sheeting joint on the road cutting in Kelok-44 at location 05PDG55.

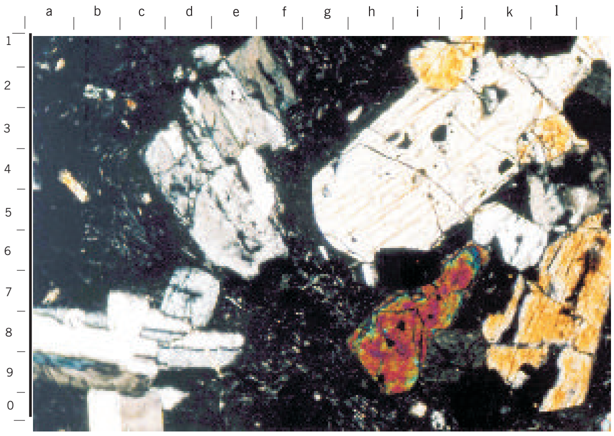

Figure 5. Andesite showing a porphyritic with phenocrist of plagioclase (d4, b8) orthopyroxene (i2, h4, k7) and olivine (h8) set in groundmass of microlith of plagioclase and pyroxene, and glass. Sample 05PDG53A.

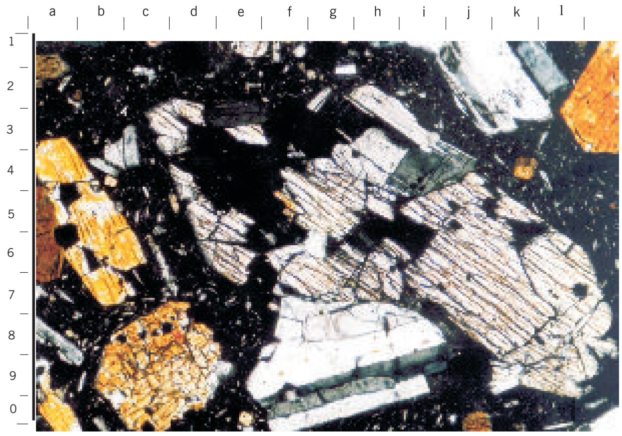

Figure 5. Andesite showing porphyritic texture with phenocrysts of plagioclase (j2, h3, f8), clinopyroxene (a4-b6, c9, a0, l1-2), orthopyroxene (e1, f4- k7) set in groundmass of glass, plagioclase and pyroxene. Pyroxenes are generally replaced by glass and shows irregular cleavage. PDG63A.

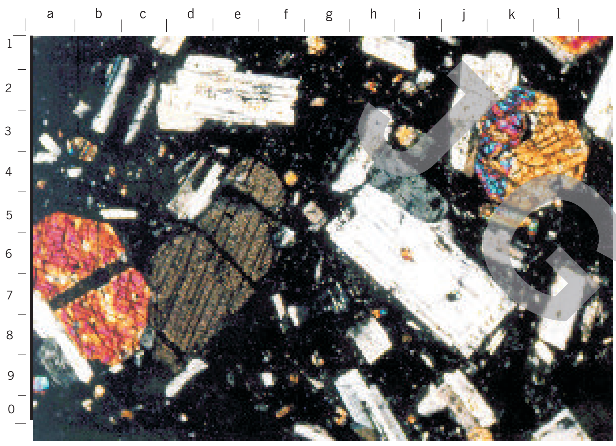

Figure 6. Andesite showing a porphyritic texture with phenocrysts of plagioclase (d2, h1, h6, g9), clinopyroxene (a7, j3, 11), orthopyroxene (d6, k3) set in groundmass of glass, plagioclase and pyroxene. Sample 05PDG55A.

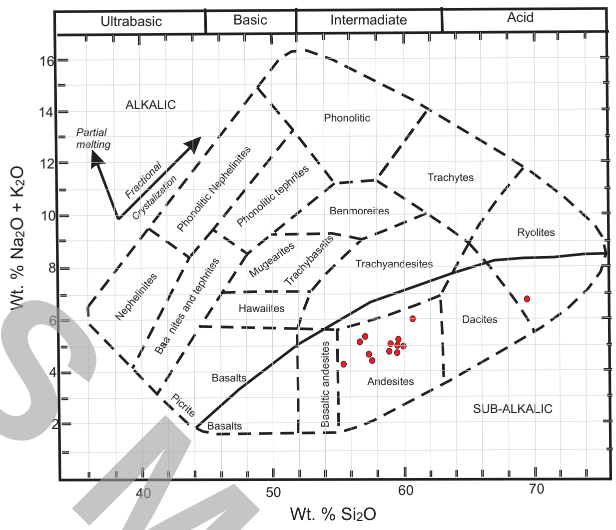

Figure 9. Nomenclature of the Pliocene Pleistocene lava andesite from Maninjau Lake West Sumatera base on SiO_2 vs K_2O+Na_2O.

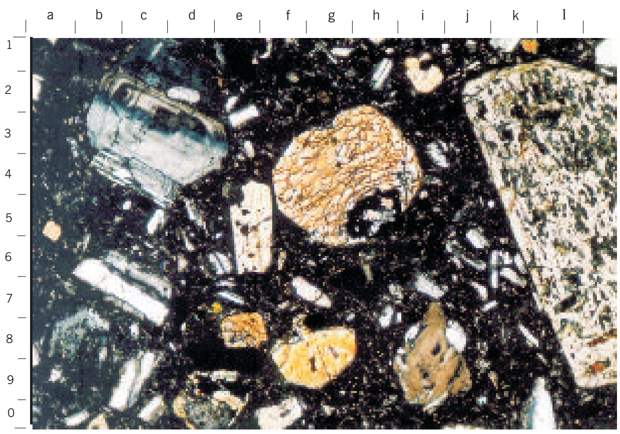

Figure 7. Andesite showing a porphyritic texture with phenocrysts of plagioclase (a3-9, j4, j2, j8), clinopyroxene (g2, h3, f6-7), orthopyroxene (d9, g4, e0) set in groundmass of glass, plagioclase and pyroxene shows irregular cleavage. Sample PDG59A.

Major Elements

The chemical characteristic of the rocks from Maninjau Lake is presented in Table 2. All quoted and plotted values presented in the following sections are the same as the value of the table. Figure 10 shows conventional classification of the lava from Maninjau Lake area based on SiO_2 vs K_2O (Peccerillo and Taylor, 1976). The rocks which belong to calc-alkaline series, are mainly of high-K affinities. Plot on AFM diagram (Figure 11) all rocks are falling on the calc-alkaline field. Most of the andesite characterized by high-Al_2O_3 content (17-18 wt%) and low-TiO_2 (<1 wt%). Their MgO concentration are also very low (maximum 4 wt%). In general wt% Na_2O is slightly greater than wt% K_2O. The rocks are high K_2O (1.6-3.27wt%) which are higher than the normal island arc calc-alkaline from Java (*i.e.* Lawu Volcanics, Hartono, 1995).They are also low in loss of ignition (LOI) that is maximum 3.50 suggesting less hydrous minerals and a fresh rock type. The whole rock Mg value (Mg# = $100Mg/Mg+Fe^{+2}$) ranges from 30 to 53, suggesting much evolved rocks. These rocks have been uniformed in composition of FeO (7 wt%), except sample 05PDG57 with value of 3 wt%, MgO (3 wt%), CaO (6 wt%) and P_2O_5 (0.14 wt%).

Trace Elements

Results of trace element analyses are presented in Table 2 and summarized on the spider diagram (Figure 12). In this diagram the trace element concentrations of rocks are divided into that of chondrites. Chondrites are used in the normal procedure, because they are primitive solar system material which may have been parental to earth. The concentration of most trace elements, especially the incompatible elements, show an increase from the most low Si andesite to rhyolite. The increasing of these elements from the basic to acid rocks might indicate that those rocks are related to each other as a parent-daughter relationship, and the rhyolite might originally be derived from the most basaltic andesite by a process of fractional crystallization. In general, trace element compositions of andesite from Maninjau Lake are almost the same as the andesite from Toba Lake (Chesner and Rose, 1991), except the elements of Ba and Sr which are lower than the Toba andesite. By comparing them with the andesite rocks from normal calc-alkaline related to subduction (Hartono, 1995), the andesite from Maninjau Lake are high in Nd, La and Rb, and low in Ba and Sr. Ni and Cr are extremely low, maximum 26 ppm and 77 ppm respectively. Rb concentrations of 43 - 100 ppm are higher than Island Arc andesite rocks of Lawu Volcano (11-70 ppm, Hartono, 1995). Ba and Sr abundances (215 - 380 ppm and 224 - 452 ppm respectively) are lower than the Quaternary andesite from the Lawu Volcano (340 - 700ppm of Ba and 370 - 565 ppm of Sr, Hartono, 1995). Figure 5 shows a pattern chondrite-normalized trace element variation diagram (spider diagram). On this diagram the Maninjau volcanic rock shows the usual characteristic of subducted-related magmatic rocks. They are in K-group element (Ba, Rb, Sr and K), Light Rare Earth Elements (LREE) (La, Ce and Nd), and depleted in high field strength elements (HFSE) (Nb,

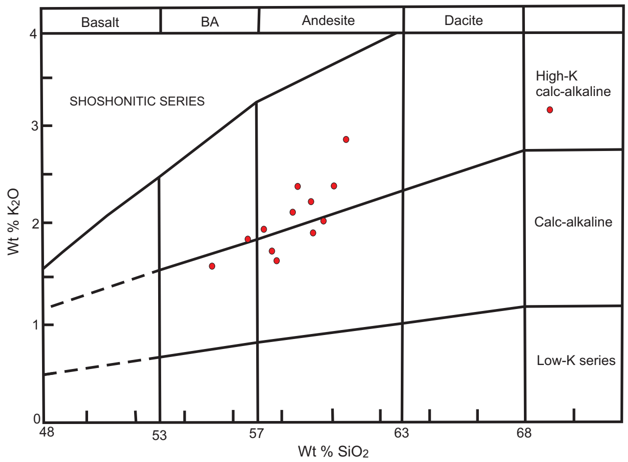

Figure 10. Plot on volcanic rocks from Maninjau Lake based on the K_2O vs SiO_2 of Pecerillo and Taylor (1976) classification scheme.

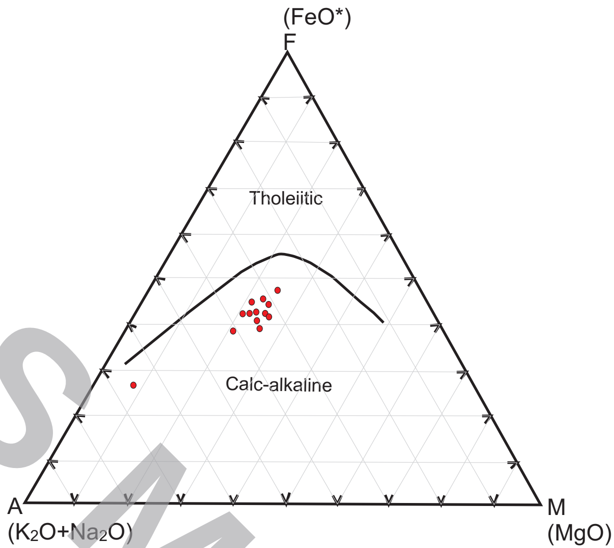

Figure 11. Plot on volcanic rocks from Maninjau Lake based on AFM diagram. The boundary between tholeiite and calk-alkaline field is taken from Irvine and Baragar (1971).

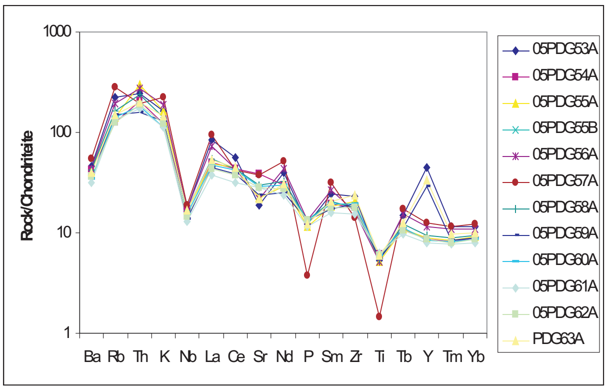

Figure 12. Spider diagram of the andesitic lava from Maninjau Lake West Sumatera.

Zr and Ti), and more compatible element (Y, Yb). The spider diagram patterns are similar to calc-alkaline that displays positive spikes at Ba, K, and Sr, and Nb through. The latter could reflect the existence of a residual Nb bearing phase in the source during the partial melting process (Wilson 1989) or the effects of crustal contamination (Cox and Hawkesworth, 1985). Nb depletion is typical of magmas erupted in subduction-related tectonic setting (Wilson, 1989). As calc-alkaline magmatism widely spread in the region of Sumatera in Oligocene - Miocene time (Cameron *et al*., 1980) it is possible that there is a subduction modified mantle source component involved in the petrogenesis of the magmas.

Rare Earth Elements and Yttrium

Rare Earth Element analyses are presented in Table 2 and the result is summarized in a spider diagram (Figure 13). This figure presents the chondrite-normalised values of a number of rare-earth elements of the lavas that show an enrichment of light rare earth element, with negative Eu anomalies. There is a marked enrichment of La, Ce, Pr, Nd, and Sm concentration, and it is flat heavy REE from Tm to Lu concentrations. The graphic shows a steep-sloping pattern from the LREE to HREE with bend in the middle REE. The most differentiated rocks (*i.e* rhyolite, 05PDG57A) paralleling the graphic pattern of andesite, suggesting the same source of rocks.

DISCUSSION

The major and trace element characteristics of the lava from Maninjau Lake areas indicate that they were generated in the subduction zone environment. The rock association is that high- K affinities, low abundance of TiO_2 and MgO, and depleted Nb relative to K and La, which are characteristic of subducted related rocks. It is worth to say that the India-Australian Oceanic Crust had been subducted beneath the Maninjau Crater areas some time in Pliocene-Pleistocene and is thought to active until the present time (Hamilton, 1979).

The main purpose of this paper is to present, for the first time, a geochemical characteristic of the lava from Maninjau Lake area. Thus, the diagram as shown on Figures 5 and 6, portray a majority of the paper's main conclusions. From these data a magmatic character of the subducted is related on the continental margin can be compared. In Java, where

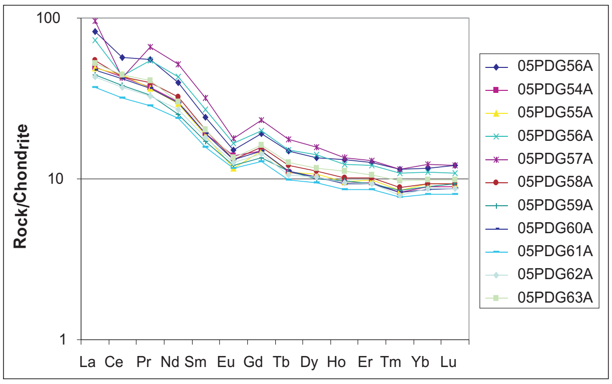

Figure 13. Rare Earth Element pattern of the lava from Maninjau Lake.

the angle of approach is at maximum, calc-alkaline volcanicity is widly spread but strike-slip motion parallel to the arc is minimal. The Sumatera sector of the arc occupies an intermediate position between these two extremes, and here the oceanic plate is being obliquely subducted. In this sector, volcanicity is well developed, but over a relatively narrow zone, and the component of strike-slip movement along the plate boundary has also induced dextral transcurrent faulting within the continental plate.

The rocks collected from the Pliocene-Pleistocene lava of Maninjau belong to magma of calc-alkaline to high-K calc-alkaline. They show a high concentration in incompatible elements and some geochemical character which are typical of island arc calc-alkaline andesites such as low Ni, V/Ni >10, high Al_2O_3%, low TiO_2 and trace elements pattern with fractionated light REE and almost flat heavy REE pattern. These characters imply that the Pliocene-Pleistocene volcanic rocks of Maninjau have been formed by a similar genetic process as island arc calc-alkaline rocks.

As mentioned in the previous section, Ba and Sr concentration in the Maninjau andesite are significantly lower than those in average island arc of Java. The characteristically great enrichment of arc lavas in Ba, Sr and Pb was proposed by *e.g*. Kay (1980) to be an indication of involvement subducted sediment in their generation.

The general characteristics of Pliocene-Pleistocene magmas from Maninjau are their high-K calc-alkaline nature, enrichment in LILE, suggesting derivation from enriched mantle source (Bailey, 1983). According to Wilson (1989) some rift basalts and more evolved lavas can clearly be related by process

Table 2. Major and Minor Element Analyses of Pliocene-Pleistocene of Volcanic Rocks from Maninjau Lake Area

	05PDG53A	05PDG53B	05PDG54A	05PDG55A	05PDG55B	05PGG56A	05PDG57A	05PDG58A
SiO2	58.87	57.18	56.86	59.84	58.46	60.37	69.28	59.88
TiO2	0.55	0.71	0.63	0.54	0.56	0.53	0.15	0.57
Al2O3	17.22	18.26	17.74	17.04	17.59	16.9	14.77	17.53
Fe2O3	6.4	7.37	7.57	6.31	6.56	6.36	3.15	6.74
MnO	0.11	0.12	0.13	0.11	0.11	0.1	0.05	0.11
CaO	5.4	6.84	6.97	5.89	5.32	5.74	1.43	5.76
MgO	3.38	3.27	4.06	3.51	3.17	2.94	0.62	2.96
Na2O	2.6	3.48	3.46	2.88	2.63	3.34	3.61	2.98
K2O	2.39	1.86	1.78	2.33	2.13	2.7	3.27	2.07
P2O5	0.13	0.19	0.14	0.12	0.11	0.14	0.04	0.14
LOI	2.74	0.69	0.59	1.43	2.86	0.87	3.55	1.15
Total	99.79	99.97	99.93	100	99.5	99.99	99.92	99.89
Rb	77.56		44.25	49.25		68.12	99.46	56.29
Ba	314.5		293.4	285.2		300	379.6	290.9
Sr	223.7		451.5	266.8		260	444.7	348.9
La	27.26		16.23	15.96		23.93	31.38	17.87
Ce	49.2		37.45	38.52		37.77	36.77	37.54
Pr	6.38		4.28	4.23		6.34	7.7	4.62
Nd	25.03		18.89	18.38		27.34	32.45	20.3
Sm	4.92		3.88	3.76		5.47	6.42	4.12
Eu	1.17		1.07	0.9		1.29	1.37	1.02
Gd	5.29		4.11	4.09		5.53	6.42	4.36
Dy	4.64		3.55	3.65		4.84	5.4	3.82
Er	2.71		2.02	2.09		2.6	2.78	2.15
Yb	2.55		1.96	2.04		2.41	2.69	2.06
Y	90.05		17.45	17.85		23.25	25.3	18.66
Zr	158.4		120.9	141.1		111.5	95.56	122.7
Nb	6.11		6.09	5.96		6	6.64	5.93
Sc	14.34		15.77	14.41		12.04	17.09	14.21
V	108.3		40.8	121.2		104.7	150	119.8
Cr	47.25		31.94	42.42		43.85	76.85	31.72
Ni	18.55		13.37	14.28		10.44	5.01	7.15
Tb	0.78		0.57	0.57		0.79	0.91	0.63
Tm	0.39		0.28	0.29		0.37	0.39	0.3
Lu	0.39		0.29	0.3		0.35	0.39	0.3
Pb	14.67		15.88	13.04		15.71	37.45	22.37
Th	10.25		8.57	12.54		11.51	8.24	9.99
U	2.05		1.48	2.09		1.89	2.78	1.73
K	19841	15440	14777	19342	17682	22414	27146	17184
Ti	3297	4256	3777	3237	3357	3177	899	3417
P	568	830	612	524	480	612	175	612
Mg#	50	47	51	53	50	47	30	47

Table 2. Continuation

	05PDG59A	05PDG60A	05PDG61A	05PDG62A	05PDG63A
SiO2	59.29	57.83	55.42	57.52	59.18
TiO2	0.57	0.61	0.66	0.61	0.61
Al2O3	17.78	18.26	18.42	18.2	17.65
Fe2O3	6.48	7.1	7.68	7.36	6.66
MnO	0.1	0.11	0.13	0.11	0.11
CaO	6.51	6.8	7.95	6.64	6.31
MgO	3.08	3.39	4.07	3.34	3.35
Na2O	2.92	2.78	2.73	2.81	2.82
K2O	1.86	1.62	1.61	1.75	2.11
P2O5	0.14	0.14	0.12	0.14	0.13
LOI	1.28	1.31	1.13	1.51	1.07
Total	100.01	99.95	99.92	99.99	100
Rb	52.87	49.46	46.17	43.44	52.09
Ba	239.6	240.6	215.6	249.9	271.7
Sr	275.9	346.8	327.9	334.4	256.9
La	14.56	15.66	12.21	14.26	17.32
Ce	33.11	36.51	27.53	32.16	38.53
Pr	3.86	4.23	3.3	3.82	4.71
Nd	15.96	18.74	14.96	17.07	19.11
Sm	3.49	3.89	3.22	3.65	4.11
Eu	0.93	1.01	0.89	0.97	1.05
Gd	3.75	4.1	3.52	3.95	4.47
Dy	3.45	3.51	3.25	3.54	3.98
Er	1.99	1.98	1.83	1.98	2.26
Yb	1.97	1.88	1.77	1.91	2.18
Y	57.99	16.75	15.81	17.44	66.21
Zr	132.1	131.7	106.8	121.6	161.9
Nb	4.78	5.37	4.55	5.05	5.89
Sc	15.62	14.38	18.4	14.43	15.35
V	129.1	123	157.6	137.9	124.9
Cr	38.32	21.32	20.12	15.02	40.66
Ni	26.07	8.27	14.31	10.35	12.3
Tb	0.58	0.58	0.51	0.55	0.66
Ho	0.71	0.68	0.63	0.69	0.81
Tm	0.29	0.28	0.26	0.27	0.33
Lu	0.3	0.28	0.26	0.28	0.32
Pb	39.8	51.8	48.07	43.37	13.86
Th	6.58	7.75	7.25	7.89	8.3
U	1.31	1.19	1.2	1.41	1.63
K	15440	13448	13365	14528	17516
Ti	3417	3657	3957	3657	3657
P	612	612	524	612	568
Mg#	50	47	50	47	50

*Mg# = MgO/MgO+FeO calc. It was calculated based on the adjustment of ferrous iron as FeO = 0.85 FeO calc.

of fractional crystallization. However, it is suggested to involve crustal rock in their petrogenesis, contamination, and AFC process.

Based on the plate tectonic model of this region (Hamilton 1979), it can be said that the Pliocene-Pleistocene volcanic products in this region were related to eastward subduction zone processes. The high-K calc-alkaline character of the rocks is probably related to subduction.

CONCLUSION

The exposed volcanic product of the Maninjau along the road from Bukit Tinggi to Lubuk Basung is mainly composed of andesite and rare rhyolite. They are highly porphyritic in texture where phenocryst of plagioclase is the dominant part followed by clinopyroxene, orthopyroxene, and opaques. Olivine mineral only occurs in one sample. Xenoliths of diorite are quite common that is made up of plagioclase and pyroxene. The product of magmatism from Maninjau was dated back to 0.8 my based on the C- dating on the ignimbrite from Bukit Tinggi area (Aspden, *et al*., 1982). Geochemical characteristics indicate that the rocks have been produced in a subduction zone environment. The lavas have narrow range in silica composition and belong to high-K calc-alkaline series. They resemble the typical of arc lavas with enrichment in large ion lithophile elements and light rare earth elements relative to high field strength elements and heavy rare earth element. The spider diagram patterns show an Nb through that resemble the arc type magma that commonly related to subduction, whether occurred in island arc or active continental margin. The lava from continental margin of Maninjau Lake has a low concentration of Ba, Sr, and La than the continental margin of Andes and the Island Arc of Java (*i.e* andesite from Lawu Volcano, Hartono, 1995). The elements of Rb, K, Ce, and Nd are high compared to the island arc of Java (*i.e* Lawu Volanics, Hartono, 1995). The Maninjau andesite characterizes a much evolved magma with Mg# of 30 to 53. The presence of magma of subducted character in Sumatera was argued to have been accounted during the eastward subduction of the India-Australia Oceanic Crust.

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