PETROLOGY AND GEOCHEMISTRY OF THE UPPER MIOCENE VOLCANICS ON THE WESTERN PART OF BARISAN MOUNTAIN RANGES, LUBUK SIKAPING REGION, WEST SUMATRA

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Abstract

Andesitic and basaltic lavas are the main product of the upper Miocene volcanic activities in Lubuk Sikaping region. They posses vesicular and amygdales structure, dark grey to black in colour, highly porphyritic in texture composed of plagioclase, clinopyroxene, orthopyroxene, olivine (in basalt only) and minor hornblende, magnetite and ilmenite. They (basalt and andesite) mostly fall within the calc-alkaline series on the AFM. The basalt and andesite are not primary magma since they have low Mg# and Ni contents. The lavas resemble the typical of arc setting with Nb through on the spider-diagram patterns, enrichment in large ion lithophile elements and light rare earth elements relative to high field strength elements and heavy rare earth element. They are co-magmatic as shown by the REE pattern. The lavas have high concentration of Ba, Sr, La, Rb and Ce, Zr, Th and U, and high Ba/La ratio which indicating an involvement subducted sediment in their generation. The lava from Lubuk Sikaping is product of Maninjau Crater eruption in Upper Miocene. This lava was uplifted and exposed on high level topography for a few million years, and then superimposed by a high-K calc-alkaline volcanic of mainly rhyolitic tuff as a result of the reactivation of the Maninjau Crater in Pleistocene.

Keywords: petrology, geochemistry, calc-alkaline, Lubuk Sikaping, tectonic

Sari

Lava andesitan dan basalan merupakan produk utama dari vulkanisme yang terjadi pada Miosen atas di daerah Lubuk Sikaping. Lava ini berstruktur vesikular dan amigdal, berwarna abu gelap sampai hitam, bertekstur porfiritik, disusun oleh mineral-mineral plagioklas, klino-piroksen, ortho-piroksen, olivin, jarang hornblenda, magnetit dan ilmenit. Selanjutnya, baik basalt dan andesit sebagian besar masuk seri kalk-alkalin dalam diagram AFM. Basalt dan andesit ini tidak dikategorikan sebagai magma primer, karena mempunyai nilai Mg# dan Ni rendah. Lava ini menyerupai tipe busur sebagaimana ditunjukkan oleh lekukan unsur Nb pada pola spider-diagram, pengayaan large ion lithophile elements dan light rare earth elements relatif terhadap high field strength elements dan heavy rare earth element. Berdasarkan pola REE, lava basalt dan andesit ini adalah co-magmatic. Lava ini mempunyai unsur-unsur Ba, Sr, La, Rb dan Ce; Zr, Th and U bernilai tinggi, selain itu perbandingan Ba/La juga tinggi, hal ini menandakan bahwa pada generasi pembentukan magma telah melibatkan sedimen yang tersubduksi. Batuan gunungapi dari Lubuk Sikaping merupakan hasil erupsi Kaldera Maninjau pada Miosen Atas. Batuan tersebut terangkat dan tersingkap pada ketinggian topografi selama beberapa juta tahun, kemudian tertindih kembali oleh volkanik kalk-alkalin K-tinggi yang sebagian besar berupa tufa rioliotik sebagai hasil reaktifasi Kaldera Maninjau pada Plistosen.

Kata kunci: petrologi, geokimia, kalk-alkalin, Lubuk Sikaping, tektonik

Introduction

Fieldwork study on magmatism in West Sumatra had been conducted in June 2005. One of the areas interested is along the road from Bukit Tinggi to Lubuk Sikaping and Panti, to study the volcanic product of Upper Miocene age (Rock *et al*., 1983).

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The study of volcanic rocks in the area was part of the research program on *Mineral Bijih Busur Magmatic* (*MBBm*) that financially supported by the Geological Research and Development Centre (GRDC) (now Centre for Geological Survey) project. The author was appointed as a project coordinator which also responsible for the petrology aspect. The area of investigation is shown on Figure 1. The Upper Miocene lavas discussed in this paper are mapped as Undifferentiated Volcanics (Tmv) (Rock *et al*., 1983) and Tertiary Andesite (basaltic) (Ta) (Kastowo *et al*., 1996). They were interpreted as one of the volcanic products of Maninjau Caldera located about 60 km west of Lubuk Sikaping town during Upper Miocene. Previous studies on magmatic rocks in the region were briefly reported by Rock et al. (1983) and Kastowo *et al*. (1996). This magmatic arc is also known as the host of epithermal gold mineralization in Bonjol and Mangani (Abidin and Harahap, 2007).

A magmatic affinities of volcanic rocks in Lubuk Sikaping region has been one of the main concerned of the *MBBm* since the region is rich in base metal, and gold was mined during Dutch colony (*i.e*. Bonjol and Mangani) (Rock *et al*., 1983; Harris, 1986; Abidin and Harahap, 2007). One of the approaches in petrogenesis study is, however, to consider volcanic composition by petrography, major, trace and rare-earth element methods in the context of tectonic environment. It is well known that the richest porphyry copper – gold (Cu-Au) deposits of Ertsberg (Papua) and ephythermal Au rich deposits of Kelian (East Kalimantan) are located on the Continental margin arc. These deposits are hosted in a high-K calk-alkaline to alkaline magma. The curiosity of the *MBBm* group in the Lubuk Sikaping areas is that, is there any giant Cu and Au deposits in this part of Bukit Barisan Zone, since it also located in the Continental margin arc. Recently, Zulkarnain (2008) reported evidence of the presence a magma source of adekitic rocks type from Bukit Barisan Zone of the Bengkulu area. This type of rock is also part of the target investigation of the *MBBm* group since it containing higher gold concentration than calc-alkaline rocks in many places such as the Phillippine (Jego, *et al*., 2006 in Zulkarnain, 2008). The study on magmatism in this area is part of the long term (7 years, 2006-2012) program on magmatism in the Bukit Barisan Zone. This paper presents new geochemical data on Upper Miocene volcanic rocks obtained from the Lubuk Sikaping region, and discusses the geochemistry and other important petrological aspects and relates them to their source and the tectonic environment, a model for its magmatic petrogenesis.

Regional Frame Work

Sumatra has been at or near an intermittently destructive plate margin since late Permian; a continuing tendency for strike-slip movement has led to the development of complex superimposed volcanic and magmatic arcs. Paleogene magmatic

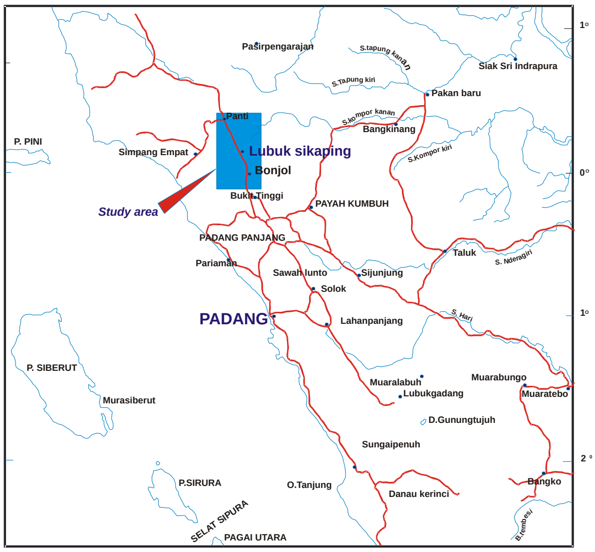

Figure 1. Geographic map of West Sumatra Province showing the location of study area.

rocks which are mainly distributed on the western part of Sumatra have tholeiitic, calk-alkaline and shoshonitic affinities (Sutanto, 2011 and Bellon et al., 2004). According to Bellon et al., (2004) there is no reflection of trend on the spatial and temporal distribution of K contents in Sumatra magmas, however the occurrence of K-rich calc-alkaline lavas seems to be more frequent during the Plio-Quaternary than before.

A brief history of events in Sumatra is that, uplift in the Barisan began in the late Middle Miocene, probably climaxed at the Mio-Pliocene boundary and has continued irregularly to the Late Pliocene (Cameron *et al*., 1980). Extensive volcanism took place over wide areas including the volcanic rocks discussed in this article. The modern geology of Sumatra began shape following the Early Pleistocene uplift. A brief period of rapid uplift of the "Barisan geanticline" has been attributed to thermal doming above large volumes of magma (Karig *et al*., 1979 and Hamilton, 1979) and a marked increase in volcanic activity followed this uplift, along with continued dextral fault motion. The thermal doming from the late Middle Miocene is attributed by Hahn and Weber (1981) to new shift in the position of the subduction zone beneath Sumatra. The area of investigation occurs within the Barisan Mountain Ranges of the West Sumatra active volcanic arc in which the Indian Oceanic Plate is currently being obliquely subducted beneath the Sundaland continental plate (Curray *et al*., 1979; Hamilton, 1979; Hutchison, 1994), with a velocity of 7.0-7.5

cm/yr (Moore *et al*., 1980) (Figure 2). The crustal type and thickness vary along the arc, from about 25-30 kilometers beneath Sumatra and West Java with continental in character (Ben Avraham and Emery, 1973) to only about 18-20 kilometers in East Java and Bali. The thickness is considered as transition between typical continental and oceanic crusts (Curray *et al*., 1979).

Regional geology of the studied area is shown in Figure 3, covers the 1:250.000 geologic map of Padang Quadrangle in the south (Kastowo et al., 1996) and Lubuk Sikaping Quadrangle in the north (Rock *et al*., 1983). The oldest rock exposed in the area is sedimentary rocks which belong to Lower Permian to Lower Carboniferous Kuantan, Kluet and Bahorok Formations of the Tapanuli Group and Mentulu Formation of the Tigapuluh Group. These formations are intruded by Permo-Triassic to Jurassic granitoid (granodiorite, granite, microdiorite and dolerite) (Tr-Jg and Jg). The Tapanuli Group is unconformably overlain by Permian-Triassic Peusangan Group which is broadly divisible into five formations: Lower Permian Palepat, Silungkang and Mengkarang Formations, and Triassic Kualu and Tuhur Formations. These two groups (Tapanuli and Peusangan) in fault contact with the Woyla Group and its correlated units (Asai, Peneta and Rawas Formations). The Woyla is formed as an oceanic assemblage interpreted as imbricated segments of ocean floor and its underlying mantle (Cameron *et al*., 1980; Rock *et al*., 1983; Kastowo *et al*., 1978). The three groups (Tapanuli, Peusangan and Woyla) and the granitoids are unconformably overlain by Tertiary to Quaternary sediments and volcanics, and intruded by granite to granodiorite of Teriary age (Tg). The youngest unit is unwelded volcanic rocks of dacitic to rhyolitic in composition products of 0.28 my (Qv). It non-conformably overlies the Upper Miocene volcanics (Tv) discussed in this paper.

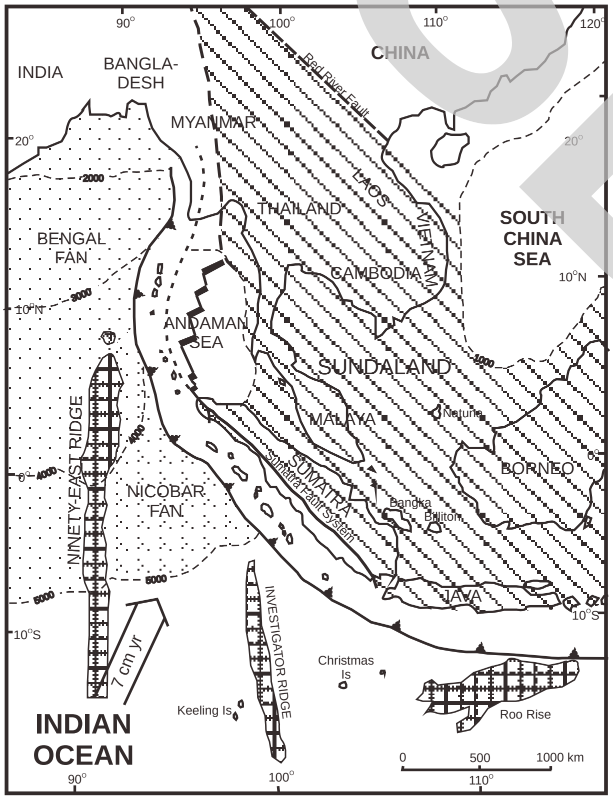

Figure 2. The tectonic setting of Sumatra with the floor of the Indian Ocean subducting beneath the southwestern margin of the Sundaland Craton. The deformation front of the Sumatran subduction system is indicated by the toolbed line; spreading centres and transform faults are shown in the Andaman Sea (after Curray *et al*., 1979).

Evidenced from the field as shown in Figure 4, contact unit between the Upper Miocene volcanic and the Pleistocene volcanic is a palaeo soil, indicating long standing paleo-topography and no continuous volcanic activity during that time. In other words, the Maninjau erupted undifferentiated volcanic products (lavas, breccias) of mainly basalt and andesite in composition in Upper Miocene (10-5 m.y). This reflects a composite paleo-volcano. In Pleistocene (0.28 m.y), the Maninjau erupted explosively to form a caldera and to produce pyroclastic rocks having dacitic–rhyolitic composition.

Analytical techniques

Major and minor (trace and rare) elements data for 19 field samples are presented in Table 1. The loss of ignition (LOI) of the rocks are low (1.0 – 4.5 wt%) which suggests a quite fresh rocks, in other word the rocks have not been altered and subjected to metamorphism. Forty one samples have been collected along the road from Bukit Tinggi to Lubuk Sikaping and Panti. All of them have been prepared manually for thin sections at the *GeolLab* of the Centre for Geological Survey and then determined petrographically through polarization microscopy at this laboratory. Geochemical analyses of the rocks including major, trace and rare earth elements were conducted at the *GeolLab*. Major element data were determined on fused glass discs by using *X-Ray Fluorescence* spectrometry. The trace and rare earth elements were performed by *Inductively Couple Plasma Spectrometry* (ICP-MS) and *Laser Ablation*. The analyses were performed by Purnama Sendjaja ST, Ronaldo Irzon ST and Irfany ST.

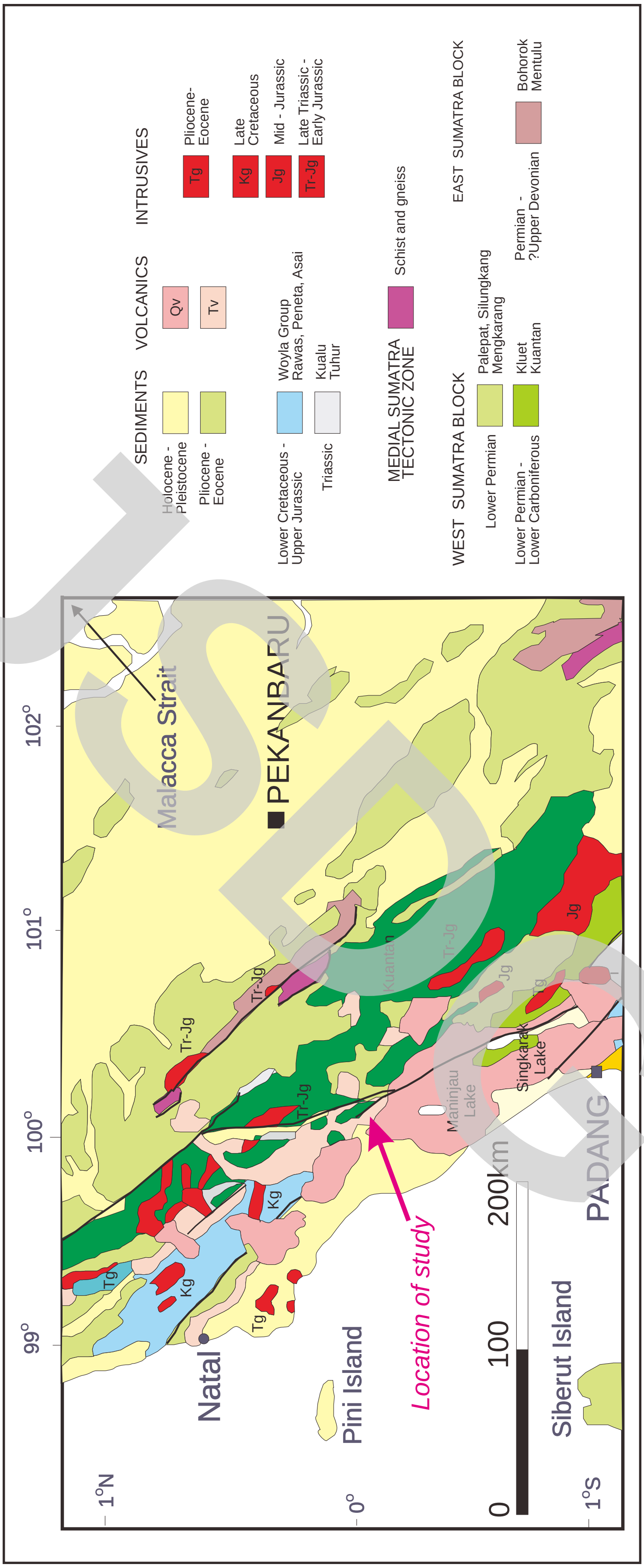

Figure 3. Regional geologic map of central part of Sumatra (modified from Crow and Barber, 2005).

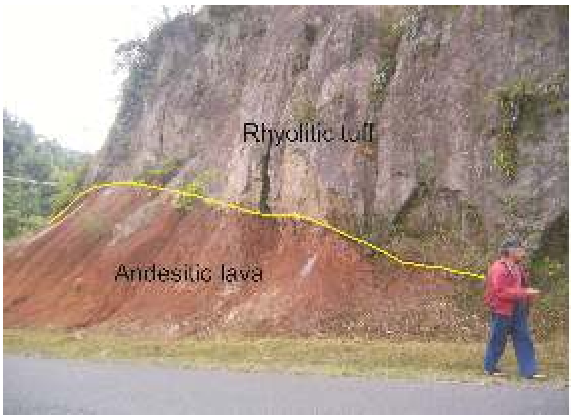

Figure 4. Contact between Upper Miocene andesitic lava (highly weathered, reddish brown in color) in the lower part and Pleistocene Maninjau rhyolitic tuff (grey color) in the upper part (Location: 05PDG35).

PETROLOGY

The Upper Miocene volcanic rocks from Lubuk Sikaping region are predominantly composed by basaltic to andesitic lavas. They are generally dark grey to reddish grey, aphanitic, hard, dense, vesicular and amygdales, layered and jointed in places. Hand specimen descriptions conform the rocks are generally fresh, medium grey to dark grey, porphyritic in texture with phenocrysts of plagioclase and pyroxene. Petrographycally (Figure 5-8), the rocks are generally quite fresh to very fresh and compose of basalt and andesite, some andesites contain xenocrysts of quartz. The andesites are porphyritic, glomerophyric and ophitic texture with phenocrysts of plagioclase, clino-pyroxene, otho-pyroxene, hornblende and rare opaques set in a groundmass of glass and microlite of same minerals as the phenocrysts. The basalt is porphyritic in texture with phenocrysts of plagioclase, olivine, clino-pyroxene and ortho-pyroxene set in a groundmass of glass and microcrystalline of plagioclase and pyroxene. The plagioclase is generally bitownite in composition and up to 0.3 x 3 mm grain size with subhedral form, often strong zoning and some grains with inclusions of pyroxene, plagioclase and opaque, sieve texture. The clino-pyroxene is subhedral, light greenish grey, zoning, maximum of 2.5 x 0.2 mm in size, some grains with inclusions of plagioclase (ophitic textures), intergrowth with plagioclase. 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 mantled by clino-pyroxene. Hornblende is yellowish brown, strongly pleochric (green to brown in colour), subhedral, up to 0.2x3.5 mm, some are replaced by opaques, some grains with inclusion of apatite. Biotite is tabular, reddish brown, up to 0.3x1.1mm. Opaque is black, euhedral to subhedral, up to 0.1x0.2mm. Olivine up to 2% in basalt, colorless, anhedral, 0.1-0.5 mm size, irregular fractured. The rocks from the study area have been classified using SiO_2 versus Na_2O + K_2O variation (e.g. Cox *et al*., 1979) (Figure 9) where 5 rocks fall within the basalt field and 14 rocks within the andesite field. They are in accordance with the petrographic analyses.

Major element data

Major element data of the volcanic rocks from Lubuk Sikaping region are presented in Table 1. The volcanic rocks from the Lubuk Sikaping classified as basalt and andesite on the silica versus alkali diagram of Cox *et al*. (1979) (Figure 9). The lavas are also illustrated under the classification of SiO_2 versus FeO_{tot} / MgO (Figure 10) of Miyashiro (1974) which shows transitional between the calc-alkaline and tholeiitic trend. The tholeiitic and calc-alkaline series are well separated in the AFM diagram (Figure 11) in which of the basalt and andesite mostly fall into a normal calc-alkaline trend and slightly tholeiitic trend. The predominantly calc-alkaline nature of the Lubuk Sikaping lavas is further illustrated by Ti versus Zr plot after Pierce and Cann (1973) (Figure 12). The basalts have relatively low FeO_{tot} / MgO (1.2-1.6), with MgO contents of 5.5-7wt%. The Mg# / Mg value [100Mg/(Mg+Fe*)] of the basalt ranges from 56 to 60. This is low compared to some MORBs that have an Mg# 70 (e.g. Wilson, 1989). Andesites have high FeO_{tot} / MgO (>2) except sample 05PDG24A (1.4 wt%) with low MgO contents 2-4 wt%), low CaO (4.50-6 wt%), and high Na_2O (3.6-4.1wt%). The Mg# of the andesite is less than 48. All of the rocks from the Lubuk Sikaping region have relatively high Al_2O_3 (17-19wt%) and low TiO_2 (0.4-0.7 wt%), and in this respect they are similar to the younger Maninjau Lavas (Harahap and Abidin, 2006). The volcanic rocks from this region have much lower P_2O_5 (0.11 – 0.31 wt%) contents than island arc tholeiites with P_2O_5 up to 0.44 wt% (Jakes and Gill, 1970). The basaltic rocks from this area, however, distinct from most high-Al basalt rocks of Java where FeO_{tot} / MgO>1.5 is common (Whitford *et al*., 1979). The low ratio FeO_{tot} / MgO of volcanic rocks from Sumatra tend to have calc-alkaline magma signature. While the high ratio FeO_{tot} / MgO of volcanic rocks from Java have tholeiitic character.

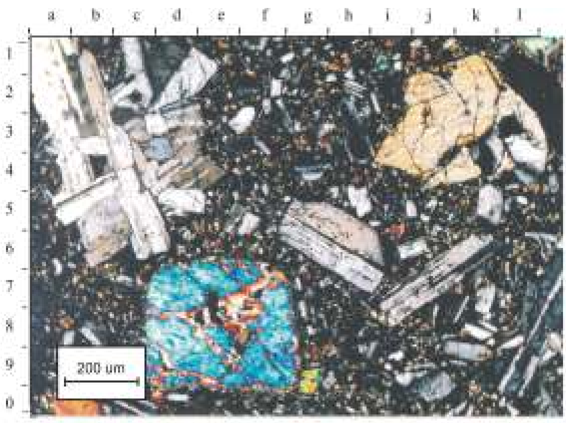

Figure 5. Basalt showing porphyritic and glomeric texture. Phenocryst of plagioclase (a1, b2-5, c2-5, g6), pyroxene (i3-j2), olivine d7-8,f7-8) set in groundmass of feldspar microlite and glass. Olivine is jacketed by pyroxene. Sample 05PDG 16B, 40x, x-nicol.

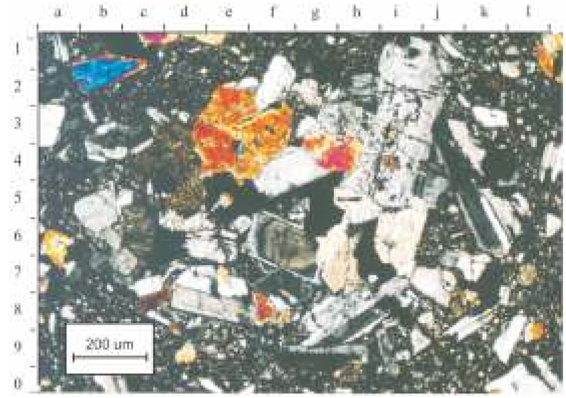

Figure 8. Glomerophyric texture in andesite shown by concentration of plagioclase(i3, g5, f7, g8, e8, j5), clinopyroxene (e3-4, g4), ortho-pyroxene (g7, i6). Olivine occur as phenocryst (b2) set in plagioclase microlite and glass.Sample 05PDG40A, 40x, x- nicol.

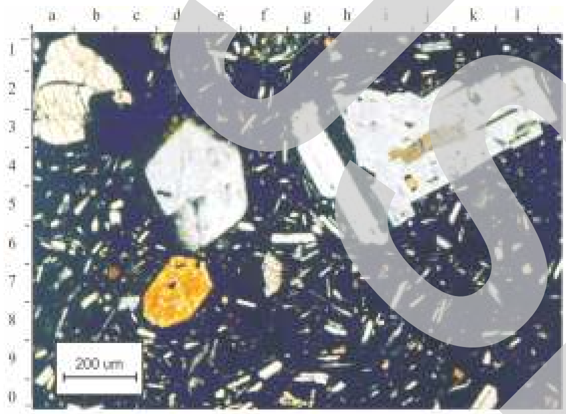

Figure 6. Basalt showing phenocryst plagioclase (i3, j3, k3, d5 and ortho-pyroxene (a2, b2, d7) sets on matrix of feldspar microlite and glass.Sample 05PDG20C, 40x, x-nicol.

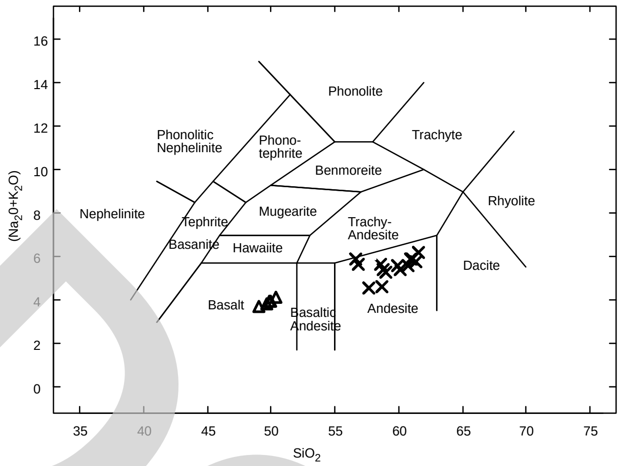

Figure 9. Nomenclature of volcanic rocks from study area (after Cox *et al.*, 1979). Symbol; x = andesite and ? = basalt.

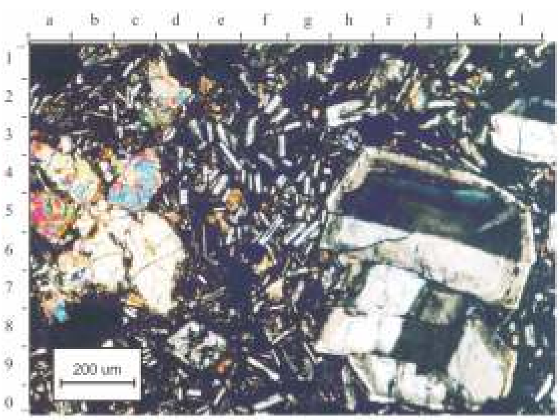

Figure 7. Andesite with porphyritic texture where phenocryst of pyroxenes (ortho and clino) (c6, a5-4, c4) and plagioclase (i5 – 8) set in microlite plagioclase, pyroxene and glass. Pyroxene shows glomerocryst texture, and plagioclase show corona texture. Sample 05PDG26A, 40x, x-nicol.

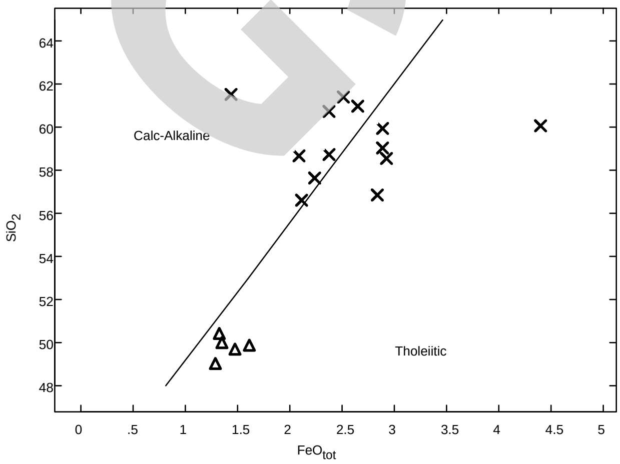

Figure 10. Classification based on FeOtot/MgO vs SiO_2 of volcanic rocks from Lubuk Sikaping region (after Miyashiro, 1974). Symbol; x = andesite and ? = basalt

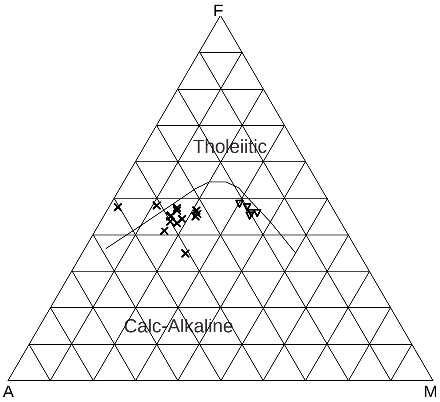

Figure 11. AFM ($K_2O + Na_2O$- FeO tot – MgO) diagram of samples from the study area (after Irvine and Baragar, 1971).Symbol; x = andesite and ? = basalt.

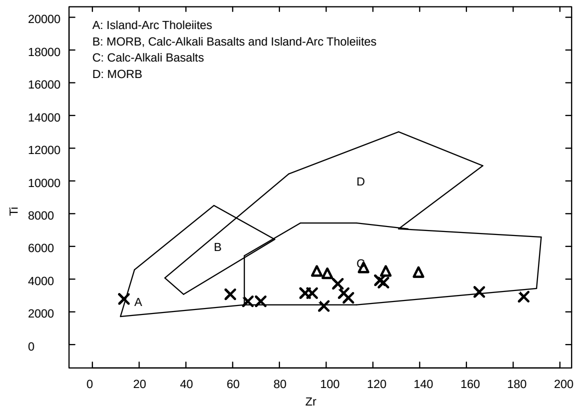

Figure 12. Plot on Zr vs Ti of the lava from Lubuk Sikaping region (after Pierce and Cann, 1973). Symbol; x = andesite and ? = basalt.

Trace Element Data

The trace element data of the volcanic rocks from the Lubuk Sikaping region are presented in Table 1. The abundance of trace element of potassium type (Ba, Sr, Rb, La, Ce) and Zr, Th and U in basalt are higher compared to average calc-alkaline association in volcanic rocks from Island Arc. Ba and Sr abundance (241-350 ppm and 325-477 ppm) are much higher than those of average calc-alkaline from Island Arc (115 and 330 ppm, Jakes and White, 1972). Rb and Zr concentrations (10-29 ppm and 78-139 ppm) are slightly higher with these average calc-alkaline associations in volcanic rocks from Island Arc (10 ppm and 100 ppm, Jakes and White, 1972). La, Ce, Th and U abundances (12.29-16.62 ppm, 27.75-35.16 ppm, 4.2-9.5 ppm and 0.83-1.09 ppm) are much higher than the calc-alkaline from island arc (9.6 ppm, 19 ppm, 1.1 ppm and 0.2 ppm). V content (44.87-132 ppm) is much lower than calc-alkaline from Island arc (255 ppm).

The characteristic features of the trace element abundance of the upper Miocene volcanic rocks from Lubuk Sikaping region are also shown on the chondrite normalized multi-element diagrams which are highly variable, particularly with respect to large ion lithophile elements (LILE) (Figure 13a, b and c). In these diagrams the trace element concentrations of rocks are divided into that of chondrite (Wood et al., 1979b in Petrelli, 2005). Chondrite is used in the normalization procedure because a primitive solar system material which may has been parental to earth. The diagram shows that those lavas characterized by moderate to high abundance of LILE (Rb, K, Zr, Th, Ba, Sr and light rare earth elements (LREE): La and Ce), and depleted in high field strength elements (HFSE: Nb and Ti). The compatible elements (Ni and Cr) are extremely low value. The Nb through is evidence in the subduction-related magmatic rocks. The low P contents are also shown by through on the diagram on Figure 13a, b and c which is typical of calk-alkaline series. The concentration of most trace elements do not show differentiation trend from basalt to andesite.

Rare Element Data

Rare earth element (REE) analyses of the lava basalt and andesite from Lubuk Sikaping region are presented in Table 1 and the result is summarized in spider diagrams (Figure 14 a, b and c). These figures present the chondrite-normalized values of a number of rare-earth elements of the lavas that show an enrichment of LREE. There is a marked enrichment of La, Ce, Pr, Nd and Sm concentration, and flat heavy REE (HREE) from Ho to Lu concentrations. The graphic shows a steep-sloping pattern from the LREE to HREE with bend in the middle REE. Chondrite normalized multi-element diagrams are less variable. The most differentiated rocks (andesite) paralleling the graphic pattern of basalt toward the HREE and crossing the basalt pattern toward the LREE, suggesting a co-magmatic with fractional crystallization processes. The lavas from Lubuk Sikaping region show the incompatible signature of arc volcanic rocks with high La/Sm (2-6) and Ba/La (15-39) compared with the mid-oceanic ridge basalt (MORB). The lavas are characterized by enrichment in LREE with (La/Yb)N varying from 3-8. The high ration of (La/Yb)N was caused by fractionation of hornblende and / or pyroxene. These lavas are typical of calc-alkaline signature rather than island tholeiite in which $(La/Yb)_N$ ratio from 1-2 (Jakes and Gill, 1970).

Table 1. Major, trace and rare element analyses of the rocks from Lubuk Sikaping Region.

Elements	05PDG14A	05PDG15A	05PDG16A	05PDG016B	05PDG17A	05PDG18A	05PDG20C	05PDG24A	05PDG26A	05PDG27A	05PDG30A	05PDG31A	05PDG32A	05PDG33A	05PDG36A	05PDG36B	05PDG37A	05PDG39A	05PDG40A
SiO2 (wt%)	49.89	49.68	49.98	50.41	49.06	58.71	60.77	61.51	59.02	59.95	56.61	57.63	61.01	60.94	61.39	58.77	60.09	56.87	58.57
TiO2	0.79	0.74	0.75	0.73	0.75	0.54	0.52	0.39	0.47	0.48	0.62	0.53	0.52	0.44	0.44	0.51	0.49	0.65	0.63
Al2O3	18.49	18.6	17.98	17.76	17.99	17.53	16.96	16.65	17.46	17.53	17.3	17.18	17.06	17.14	17.23	17.3	18.04	18.36	18.09
Fe2O3	9.05	9.15	9.2	9.06	9.19	6.28	6.26	5.3	6.16	6.34	8.27	6.59	6.39	5.56	5.56	6.47	6.33	7.06	7.26
MnO	0.16	0.17	0.16	0.16	0.16	0.11	0.12	0.12	0.1	0.1	0.19	0.11	0.13	0.11	0.11	0.11	0.09	0.12	0.13
CaO	8.62	8.96	9.8	9.84	10.12	4.5	5.25	5.54	5.5	5.88	6.31	5.77	4.75	4.66	4.91	5.66	4.69	5.95	5.41
MgO	5.63	6.21	6.83	6.83	7.13	3	2.63	3.7	2.13	2.2	3.91	2.95	2.41	0.23	2.21	2.73	1.44	2.49	2.48
Na2O	3.1	2.88	2.94	3.06	2.81	2.49	3.64	4.03	3.48	3.46	3.6	3.46	3.6	3.36	3.29	3.39	3.37	3.97	3.8
K2O	0.86	0.95	1.02	1.05	0.88	2.15	1.97	2.16	1.82	2.1	2.26	1.1	2.26	2.52	2.49	2.02	2.04	1.65	1.82
P2O5	0.23	0.26	0.23	0.26	0.22	0.28	0.12	0.11	0.17	0.17	0.15	0.15	0.16	0.13	0.12	0.16	0.17	0.31	0.22
LOI	3.09	2.4	1.06	0.81	1.63	4.45	1.85	1.69	2.44	1.13	1.27	3.48	1.06	2.53	2.2	2.86	3.17	2.57	1.52
Total	99.91	100	99.95	99.97	99.94	100.04	100.09	101.2	98.75	99.34	100.49	98.95	99.35	97.62	99.95	99.98	99.92	100	99.93
Rb (ppm)	29.16	12.88	20.62	13.4	9.87	3	45.76	49.48	22.07	38.51	38.4	20.76	41.82	40.23	49.23	26.86	56.57	20.37	9.24
Ba	350.4	263.6	246.9	241	202.5	330.5	332.6	413.3	361.3	371	300.6	309.5	449.5	341	348.7	214	510.9	331.3	249.6
Sr	477	421.7	396.5	467.1	393.7	234.4	267.6	328	86.04	110.9	327.9	253.7	115.6	343.3	270.1	117.4	346.9	431	514.2
La	15.96	16.23	16.62	14.08	12.29	19.02	16.79	21.15	16.22	14.91	15.95	12.18	16.12	17.44	16.47	13.13	13.12	21.29	15.08
Ce	32.44	35.16	34.67	30.97	27.75	44.01	33.02	37.43	34.79	31.37	31.67	26.71	34.16	28.65	29.1	29.14	28.11	41.57	34.13
Pr	3.68	4.23	4.04	3.49	3.04	5	3.54	4.58	3.4	3.28	3.62	3.21	3.56	3.97	3.49	3.5	2.84	5.84	3.98
Nd	16.41	17.51	16.8	15.63	13.5	19.78	13.55	18.58	13.28	13.64	14.49	13.04	14.71	16.7	13.15	15.76	11.22	27.76	17.77
Sm	3.33	3.7	3.39	3.13	2.72	4.12	2.71	3.8	2.55	2.66	3.01	2.89	2.85	3.18	2.55	3.42	2.16	6.5	3.59
Eu	1.11	1.15	1.06	0.98	0.82	0.98	0.86	1.19	0.8	0.87	0.97	0.93	0.94	1	0.7	1.07	0.79	2.03	1.11
Gd	4	3.86	3.69	3.36	2.95	4.3	3	4.54	2.9	2.99	3.36	3.11	3.19	3.45	2.71	3.8	2.29	7.19	3.78
Dy	3.98	3.54	3.31	2.97	2.53	3.85	2.69	4.41	2.51	2.64	3.1	2.8	2.76	2.94	2.31	3.36	1.89	6.67	3.27
Er	2.71	2.03	1.89	1.69	1.49	2.19	1.63	2.94	1.49	1.58	1.86	1.61	1.61	1.68	1.35	1.88	1.08	3.65	1.85
Yb	2.94	2.02	1.87	1.67	1.46	2.19	1.68	2.83	1.59	1.62	1.83	1.62	1.69	1.69	1.37	1.84	1.09	3.69	1.77
Y	23.43	58.06	55.21	14.47	12.29	64.17	46.89	99.63	12.84	15.14	60.25	45.02	14.62	14.5	39.46	16.56	10.83	30.51	15.82
Zr	116.2	139.4	125.4	100.4	96.04	165.7	93.9	99	13.7	109.5	105	91.12	107.3	71.9	66.68	59.11	184.7	122.9	124.5
Nb	6.42	5.72	5.73	6.09	5.75	6.28	6.17	6.5	7.46	6.58	5.35	5.56	7.21	6.01	5.74	6.3	6.79	6.15	6.14
Sc	11.32	22.34	22.32	20.5	18.26	15.69	14.35	12.52	13.45	10.03	18.86	13.17	10.67	12.46	11.13	20.22	10.81	12.68	19.41
V	132.3	47.7	48.86	45.98	44.87	119.8	131.6	108.2	115.8	110.9	157.3	116	118.8	110.5	89.82	58.59	107.7	116.2	42.98
Cr	14.66	151.4	155.4	174.1	177.1	35.3	188.5	112.7	107.1	27.36	81.5	45.06	36.11	56.4	65.89	24.12		18.11	104.6
Ni	7.93	64.08	70.27	65.6	65.14	15.82	270.5	64.65	11.65		23.53	19.29		20.89	11.04	0.37		2.28	45.3
Tb	0.59	0.58	0.56	0.47	0.4	0.64	0.44	0.69	0.39	0.4	0.5	0.46	0.42	0.47	0.39	0.52	0.3	1.04	0.52
Ho	0.85	0.72	0.67	0.58	0.5	0.79	0.57	0.99	0.49	0.53	0.64	0.57	0.54	0.57	0.48	0.65	0.37	1.27	0.63
Tm	0.41	0.3	0.28	0.25	0.21	0.33	0.25	0.43	0.21	0.22	0.27	0.24	0.23	0.24	0.2	0.26	0.15	0.52	0.26
Lu	0.49	0.31	0.28	0.25	0.21	0.33	0.27	0.47	0.22	0.23	0.29	0.25	0.24	0.25	0.21	0.26	0.16	0.54	0.26
Pb	15.57	84.64	15.01	14.27	112.5	12.75	13.15	44.83	15.75	8.95	14.59	34.63	34.17	51.51	16.76	13	47.01	9.53	21.16
Th	5.81	3.77	4.31	5.78	4.23	11.47	7.94	6.53	9.07	6.68	5.47	4.92	7.78	7.16	6.03	5.57	5.76	5.19	3.73
U	1.09	0.83	0.92	0.94	0.91	2.15	1.78	1.46	2.15	1.6	1.17	1.09	1.91	1.36	1.31	1.01	1.68	0.9	0.73
(La/Sm)N	2.63	2.41	2.69	2.47	2.48	2.53	3.40	3.05	3.49	3.07	2.91	2.31	3.10	3.00	3.54	2.11	3.33	1.80	2.30
(La/Yb)N	3.29	4.87	5.39	5.11	5.10	5.26	6.06	4.53	6.18	5.58	5.28	4.56	5.78	6.25	7.29	4.32	7.29	3.50	5.16
Ba/La	22.00	16.20	15.00	17.10	16.50	17.40	19.80	19.50	22.30	24.90	18.80	25.40	27.90	19.60	21.20	16.30	38.90	15.60	16.60

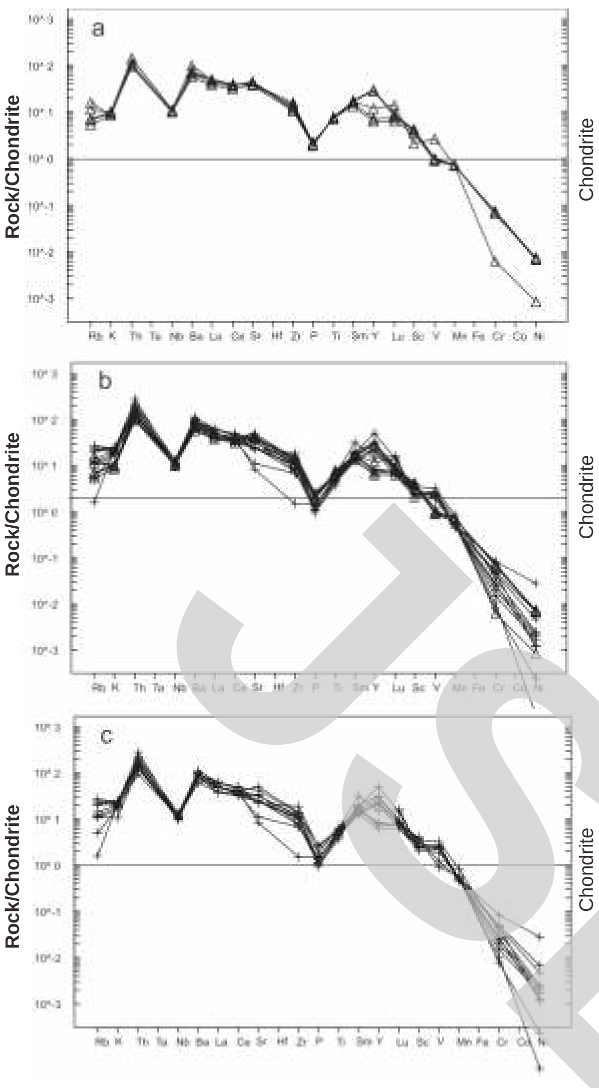

Figure 13. Spider diagram of trace element composition of basalt (a), andesite (b) and combination of a and b (c) from Lubuk Sikaping region normalize onto Chondrite (after Wood, 1979b in Petrelli, 2005). Symbol: + = andesite and ? = basalt.

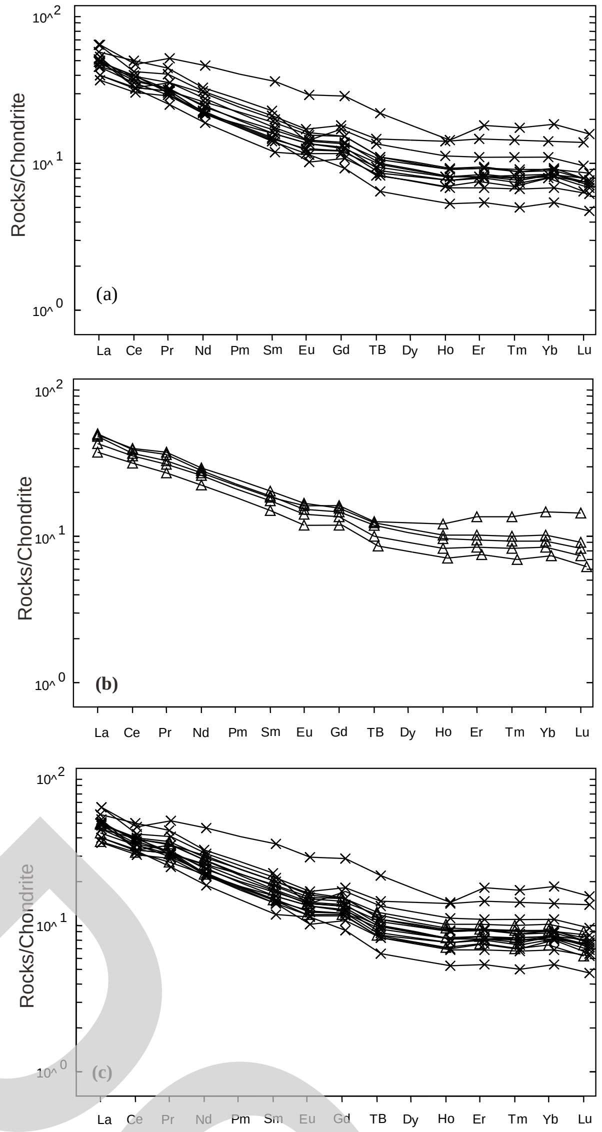

Figure 14. REE diagram of the samples from study area, normalized into chondrite (after Haskin et al, 1968 in Petrelli, 2005). Symbol; + = andesite and ? = basalt. Depleted pattern of some andesite compared with the basalt should be noted. In general, the basalt and andesite range from flat to LREE enriched patterns.

DISCUSSIONS

The Upper Miocene andesite and basalt lavas from Lubuk Sikaping region have been interpreted by Rock et al. (1983) to be the oldest product or probably the initial stage of the Maninjau paleo-volcano eruption. They are non-conformably overlain by the Pleistocene Maninjau Tuff (Figure 4) forming a volcanic belt along the Bukit Barisan Range. The formation of Sumatran Fault System two million years ago at the time was generally collinear with the volcanic belt (Nishimura *et al*., 1984) seems that not related to the Upper Miocene Undifferentiated volcanics. Intrusions of dacitic composition centered on Bonjol are interpreted to be related to the tensional field associated with the Sumatran Fault Zone, intruded the Upper Miocene Undifferentiated volcanics (Rock *et al*., 1983). The gold occurrence in this area is believed to be related with this dacitic volcanic rock (Harris, 1986; Abidin and Harahap, 2007).

A characteristic feature of the volcanic rocks from the Lubuk Sikaping region is their highly porphyritic nature with phenocrysts of olivine, pyroxene, plagioclase, hornblende and biotite. The commonly presence of olivine in the most basic rocks (basalt) accompanied by clino-pyroxene and plagioclase, and the commonly presence of ortho-pyroxene, clino-pyroxene, plagioclase, hornblende and rare biotite in andesite is one of the evidence of fractional crystallization had occurred in the magmas (Ewart, 1982 in Wilson, 1989, pg. 169). Other evidence for the crystal fractionation in this volcanic rock is shown by hornblende and groundmasses, and olivine mantled or blanketed by clino-pyroxene as well. The hornblende in the andesite is strong pleochroic varying from green to brown in colour, and frequently showing intense opaque reaction rims due to low-pressure instability. Groundmass in the basalt and andesite is glass and microlith of the same minerals as phenocrysts.

The evidences of geochemistry show that basalt samples are tholeiitic and the andesite calk-alkaline and tholeiitic on the SiO_2 versus FeO_{tot}/MgO diagram (Myashiro, 1974; Figure 10). While on the AFM diagram (Irvine and Baragar, 1971; Figure 11) most of the volcanic rocks fall in the calc-alkaline field. According to tectonic discriminates Zr versus Ti diagram (Pierce and Cann, 1973; Figure 12) the lavas are mainly fallen on the calk-alkali basalts and Island-Arc Tholeiites field, indicating an arc environment. These lavas have low abundance of TiO_2 and MgO, and depleted Nb relative to K and La, are characteristic feature of subducted related rocks. They show a high concentration in incompatible elements and some geochemical characters which are typical of island arc calc-alkaline volcanics such as low Ni, V/Ni >10, high Al_2O_3, and trace elements pattern with fractionated LREE and almost flat HREE pattern. These characters suggest that the upper Miocene volcanic rocks of Lubuk Sikaping have been formed by a similar genetic process as arc calc-alkaline rocks. The parent magma of calk-alkaline has been stated by many petrologists *i.e*. Myashiro (1974) to be generated by partial melting of peridotite in the upper mantle wedge overlying a descending slab. The enrichment of low ionic potential (Sr, K, Rb, Ba, Th and U) have been attributed to metasomatism of their mantle source region by hydrous fluids derived from the subducted oceanic crust. According to Wilson (1989) in some rift basalts and more evolved lavas it can be clearly related by process of fractional crystallization. However there is the involvement of crustal rock in their petrogenesis, contamination and AFC (assimilation and fractional crystallization) process. As mentioned in the previous section, Ba and Sr concentrations in the andesite from Lubuk Sikaping region are significantly higher than those in average calc-alkaline and tholeiite island arc of Java. The characteristically great enrichment of arc lavas in Ba, Sr and Pb are proposed by Kay (1980) to be an indication of involvement subducted sediment in their generation. The high Ba and Ba/La ratios are also argued by Hartono (1994) as the involvement of sediment in the magma source as subducting materials.

Based on the plate tectonic model proposed in Sumatra (*i.e*. Hamilton, 1979), the two volcanics (Upper Miocene and Pleistocene) erupted from Maninjau Crater are related to subduction process, the Indian Plate subducted underneath Sumatra Island. So, it is worth to mention that these two volcanics should be derived from the same magmatic source. Lithologically, the Upper Miocene Undifferentiated volcanic of the Maninjau products from Lubuk Sikaping (in this study) is predominantly composed of basalt and andesite, while the Pleistocene volcanic product from Maninjau Crater reported by Kastowo *et al*. (1996) are dominated by pumice tuff of rhyolitic composition. In the case of their geochemical composition, the Upper Miocene volcanic is slightly tholeiitic character with lower K_2O content than the Pleistocene volcanics.

This paper will not discuss any further about the petrogenetic relationship of these two volcanic rocks. It is suggested that to conduct more work in this area, firstly to study the relationship of the Tertiary and Quaternary magmatic rocks with the base metal occurrence, secondly to study the relationship of magmatic product of the Maninjau Crater during Tertiary and Quaternary period, thirdly to conduct radiometric age dating to Tertiary magmatic rock unit and fourthly to clarify the absence of basaltic andesite magma as reported in this article.

The unit status of the volcanic rocks discussed in this article has not been synchronous between the two geologic maps; andesite (Ta) on the Padang (Kastowo *et al*., 1996) and undifferentiated volcanics (Tmv) on the Lubuk Sikaping (Rock *et al*., 1983) Quadrangles. Based on this study both are lava flows resulting from eruption of the Maninjau crater during Tertiary period. The absence of basaltic andesite from this study is thought to be, for the time being, caused by miss of sample collection in the field, since the traverses was not adjusted with vertical section, as had been done for the Maninjau Lake area (Harahap and Abidin, 1996).

Conclusions

The exposed volcanic product of the upper Miocene undifferentiated volcanics along the road from Bukit Tinggi to Lubuk Sikaping is mainly composed of andesite and basalt. They are highly porphyritic in texture where phenocryst of plagioclase is the dominant part followed by clino-pyroxene, ortho-pyroxene, olivine, hornblende and opaques. Biotite mineral only occurs in one sample.

The evidence of geochemistry shows that the rocks belong to calc-alkaline series. The Lubuk Sikaping basalt lavas characterized Mg# of 56-60 and the andesite is a much evolved magma with Mg# of <48 which suggests they are not in equilibrium with upper mantle magma, and also the low Ni contents suggests that they are not primary magma and have undergone olivine fractionation en route to the surface. Geochemical characteristics suggest that the rocks have been generated by partial melting of peridotite. They resemble to the typical of arc lavas produced in a subduction environment, 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 commonly found in active continental margin and island arc environment. The volcanic from Lubuk Sikaping region are rich in Ba, Sr, Pb and high Ba/La ratio indicating that there is an involvement subducted sediment in their generation. The REE pattern of the andesite and basalt from Lubuk Sikaping region shows that they are co-magmatic and indicate fractional crystallization processes.

Two volcanics (Undifferentiated volcanics and Maninjau Tuffs) are product of the Maninjau Crater eruption in Upper Miocene and Pleistocene respectively. The Upper Miocene calc-alkaline lava was uplifted and exposed on high level topography, and then superimposed by a high-K calc-alkaline volcanic of mainly rhyolitic tuff as a result of the reactivation of this crater in Pleistocene.

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