The origin of Cihara granodiorite from South Banten

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Abstract

Petrographical and geochemical characteristics of the Late Oligocene Cihara Granodiorite from South Banten are presented. Data show that the rock was originated from magma of a continental origin formed at a subduction zone environment. Fractional crystallization involving plagioclase, hornblende, pyroxene, and magnetite was the main process responsible for the geochemical variation of the rocks from the Cihara Granodiorite. There are two possibilities of parental magmas to the Cihara Granodiorite, *i.e.* the basaltic/ or andesitic magma of the Cikotok Formation or crustal melting magma from a subduction process. Some trace element data of the basaltic rocks from the Cikotok Formation are needed to support the first interpretation. Alternatively, heating of the Jawa lower crust by magma from either mantle or subducted slab melting caused the crustal melting to produce intermediate parent magma. Some degree of mixing between those two different magma sources during the fractionation may be involved in the petrogenesis.

Keywords: Cihara Granodiorite, subduction zone, crustal melting magma, fractional crystallization

Sari

Ciri petrografi dan geokimia batuan Granodiorit Cihara berumur Oligosen Akhir dari Banten Selatan disajikan. Data menunjukkan bahwa batuan ini berasal dari magma asal kontinen yang terbentuk di daerah penunjaman. Fraksinasi kristalisasi yang melibatkan plagioklas, horenblenda, piroksen, dan magnetit adalah sebagai proses utama yang mengakibatkan variasi geokimia batuan Granodiorit Cihara. Ada dua kemungkinan magma induk Granodiorit Cihara, yaitu, magma basaltik/andesitik Formasi Cikotok atau magma hasil peleburan kerak akibat proses penunjaman. Data sejumlah unsur jejak batuan basaltik dari Formasi Cikotok diperlukan untuk menunjang interpretasi pertama. Alternatif lain, pemanasan kerak bawah Pulau Jawa oleh magma hasil peleburan mantel atau kerak yang menunjam akan mengakibatkan peleburan dan menghasilkan magma berkomposisi menengah. Pada tingkat tertentu telah terjadi percampuran antara kedua magma yang berbeda sumber itu di dalam proses petrogenesis.

***Kata kunci**: Granodiorit Cihara, zona penunjaman, magma asal kontinen, kristalisasi fraksinasi*

Introduction

The origin of granitic rocks, especially their sources and processes by which the granitic rocks are formed and emplaced to the earth crust are still widely discussed among petrologists. Before 1960s many petrologists believed that some granites might be originated by a metasomatic process, which was known as granitization. This opinion basically proposed that sedimentary or other non-granitic rocks could be transformed into granite without going through a melt stage (for example: Chayes, 1952). However since a comprehensive experimental study on the relevant phase relations by Tuttle and Bowen (1958), the granitization hypothesis has been less popular.

The migmatite (introduced by Sederholm, 1907) complexes, an intimate mixture of granite and metamorphic rocks that previously has been interpreted as a metamorphic product, would now been

believed as a magmatic fraction. The fact that there is a corresponding composition between granite and rhyolite suggests that granite magma must be the product of either partial melting or crystallization differentiation. The source involved in the partial melting could either be sedimentary rocks and their metamorphic equivalent or igneous rocks of basic to intermediate composition. Granitic magmas can not be derived from anhydrous ultramafic source rocks at a pressure equivalent to lower crust or upper mantle depths. However, in a hydrous condition (Kushiro, 1972), partial melting of garnet lherzolite at a depth about 80 km could result in a hydrous granodioritic liquid. The granitic magma might also be derived from a parent basaltic liquid by a process of fractional crystallization. More extensive studies on chemical characteristics of the granitoid rocks (*e.g.* White and Chappel, 1977; Clarke, 1992; Pitcher, 1993; Winter, 2001) reveal that there is a relationship between granite types and their tectonic environment as well as their sources.

The presence of granodiorite rock in Bayah area has been reported by several authors (*e.g.*, Koolhoven, 1933; van Bemmelen, 1949; Sujatmiko and Santosa, 1992). However, none of those authors have reported about the origin. The Cihara Granodiorite is a batholith exposed in Cipeusing and Cigaber Rivers, Bayah area (Figure 1), that belongs to the 1 : 100.000 Geological Map of Leuwidamar (Sujatmiko and Santosa, 1992). The unit is Late Oligocene – Early Miocene in age (Koolhoven, 1933), consisting of granodiorite, granite, dacite porphyry and aplite (van Bemmelen, 1949; Sujatmiko and Santosa, 1992). The youngest formation intruded by these granitic rocks is the Cikotok Formation which mainly consists of volcanic products such as lavas, volcanic breccias, and tuffs of andesitic to basaltic composition (van Bemmelen, 1949). There is no detailed petrological and geochemical study on the Cihara rocks has been reported. This paper presents petrographical and geochemical data of the Cihara Granodiorite and discusses the magmatic origin and evolution. The data upon which this paper is based was obtained during the 2005 Geophysical Research Project on the basement configuration of the Bayah area by the Geological Research and Development Centre (now the Geological Survey Institute) as well as data from a graduate research of the third author in the Padjadjaran University.

Figure 1. Map of western Jawa, Indonesia showing the location of the study area (red rectangle).

Sampling and Analytical Methods

Rock samples were collected from the field for petrographic and chemical study purposes. Although taken by a hammer, a careful selection of rocks has been done to ensure that they were as fresh as possible. Twenty three samples were analyzed for petrographic studies and the results are presented in this paper. The complete results of petrographic description are available on request to the third author.

Weathered surfaces were removed before rock samples were crushed into coarse-grained gravels in a steel jaw crusher for geochemical analysis. Major, trace and rare earth element analyses were done in Geolabs, Geological Survey Institute in Bandung. Major elements of the Cihara Granodiorite were determined by an Automated X-Ray Fluorescence Thermo ARL advanced XP Spectrometer, while the trace and rare earth elements were analyzed using a Thermo Elemental ICP-MS.

Geology

From the Early Tertiary (Lower Eocene) to Late Pliocene, the geology of the study area was characterized by sea level transgression and regression, which were dominated by a shallow marine, paralic to terrestrial clastic and carbonate sediments intercalated by and/ or interfingering with volcanics

such as tuffs, volcanic sandstones, and lavas.

The oldest sedimentary formation, Lower Eocene Bayah Formation (Hadiwisastra *et al.*, 1979; Koolhoven, 1933) consists of paralic fine to coarse clastic sediments of claystone, tuff, sandstone and conglomerate, overlain by neritic limestone on the top of the formation. Uplifting of the area during Late Eocene is indicated by a series of littoral to paralic clastic sediments of quartz sandstone, conglomerate, and claystone of the Cicarucup Formation (Koolhoven, 1933).

Continuous uplifting during this time cause an erosional stratigraphic gap between the Cicarucup Formation and the younger Oligocene Cijengkol Formation (Sujatmiko and Santosa, 1992; Koolhoven, 1933). The Cijengkol Formation consists of paralic sediments of sandstone, conglomerate, volcanic breccia, tuff, and coal bed intercalations at the bottom followed by shallow marine deposits consisting of marl and limestone. The marine deposition continuous to mid Lower Miocene producing limestone, marl and sandstone at the bottom and tuff, volcanic breccia, sandstone, conglomerate, and sandstone of the Citarate Formation. Simultaneous volcanic activity occurred during the sedimentary processes since Late Eocene to Early Miocene producing pyroclastics and lava (the Cikotok Formation) which interfinger with the sediments (Sujatmiko and Santosa, 1992). The pyroclastic deposits (volcanic breccia and tuff) as well as lava are andesitic to basaltic in composition. The Cikotok Formation is intruded by granodiorite (van Bemmelen, 1949) of Late Oligocene – Early Miocene in age (Koolhoven, 1933) called the Cihara Granodiorite (Sujatmiko and Santosa, 1992). In the study area, the Cikotok Formation is unconformably overlain by Miocene marine clastic sediments and limestone of the Cimapag Formation and Pliocene pyroclastic deposits and lava of the Malingping tuff (Ardiansyah, 2007).

The formation of Bayah Dome (van Bemmelen, 1949) was possibly started in the Late Paleogene and caused by a tectonic activity that resulted in a Late Paleogene unconformity in the Bayah area. Van Bemmelen (*op. cit.*) further suggested that the formation of the Bayah dome continues until the Middle Miocene. However, there was no tectonic event in this time, and based on stratigraphic relationship (Sujatmiko and Santosa, 1992) a tectonic activity probably occurred in the Late Miocene.

The Late Paleogene tectonic activity was simultaneous with magmatism that produced pyroclastic and other volcaniclastic sediments (the Cikasungka Formation of Sujatmiko and Santosa, 1992) and a series of andesitic to dacitic shallow intrusives or subvolcanic rocks. The paleogeography of South Banten has not been changed until the Miocene time, that is characterized by a shallow marine to paralic sediments (the Citarate to Bojongmanik Formations: see Sujatmiko and Santosa for detailed stratigraphic information).

A more extensive magmatism occurred during the Pliocene which produced pyroclastic deposits and minor andesitic lavas of the Malingping Tuff, Citorek Tuff, and Genteng Formation (Sujatmiko and Santosa, 1992), which was mostly deposited in terrestrial to paralic environments. This magmatism was followed by a tectonic uplifting of the Bayah area in the Late Pliocene which, according to van Bemmelen (1949), resulted in the Bayah Dome. This tectonic uplifting also resulted in a stratigraphic gap between the Lower – Upper Pliocene Malingping Tuff and marine to terrestrial deposits of the Upper Pliocene Cipacar Formation. In the Pleistocene, the shallow marine deposits of calcareous sandstone, marl, sandy clay, and limestone lenses predominated the lower part (the Bojong Formation). This series of rocks are interfingering with volcanic breccia, lava and tuff of the Endut Volcanics. The volcanism seems to be continuous up to the Late Pliocene producing Tapos Breccia, Halimun lava, and olivine basalts, which possibly part of the Halimun lava.

ANALYSIS RESULTS

Petrography

Twenty three samples of the Cihara Granodiorite were analyzed for petrographic studies and these rocks are classified as granite, granodiorite, aplite, and diorite. Detailed petrographic descriptions are available on request to the third author. Most of the rocks are coarse-grained holocrystalline, and only few are slightly porphyritic with groundmass of similar composition to the phenocrysts, consisting of plagioclase, orthoclase, ortho- and clinopyroxene or hornblende, quartz, magnetite, and minor biotite. Specific textures are sometimes found in several

thin sections, such as sieve textures (Figure 2), plagioclase reaction rims (Figure 3), and plagioclase resorpsions and quartz embayment (Figure 4). Most of the crystals, except quartz, are subhedral and some are euhedral, evenly distributed throughout the sections, although some samples show glomerophyric textures.

Geochemistry

Three samples have been analyzed for major and trace elements in this study, and the results are presented in Table 1 and several figures in this paper. The Cihara Granodiorite is intermediate to acid with silica contents ranging from 55 to 74 wt %, and belongs to calc-alkaline series (Figures 5 and 6) characterizing subduction related

magmatic origin. Low abundance of aluminum contents (13.0 – 17.4 wt %) is also a characteristic of the rocks. The ratios of aluminum-alkali and aluminum calcium alkali of the rocks (Figure 7) suggest a metaluminous-peraluminous series (Malinar and Piccoli, 1989). The subducted related magmatic origin is also supported by the trace element data. Compared to the MORB, the Cihara Granodiorite has a higher concentration of large ion lithophile elements (LILE: Ba, Rb, Th), but the HFSE (Nb) is comparable (Figure 8). Other HFSE (Ti and Zr) concentrations of Cihara rocks are even lower than that of MORB.

Figure 2. Plagioclase sieve textures in the Cihara Granodiorite.

Figure 3. Plagioclase reaction rims in the Cihara Granodiorite.
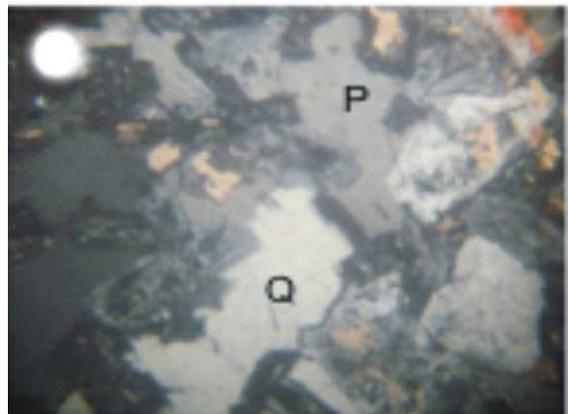
Figure 4. Plagioclase resorpsion (P) and quartz embayment (Q) in the Cihara Granodiorite.
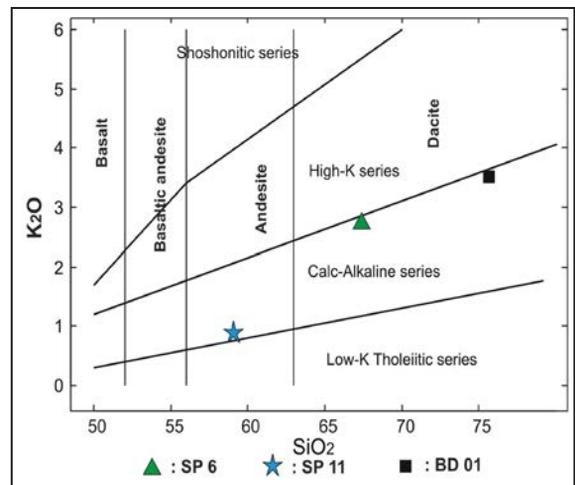
Figure 5. SiO_2 vs. K_2O of the Cihara Granodiorite. The boundary between low-K tholeiite, calc-alkaline, high-K, and shoshonitic series are of Pecerillo and Taylor (1976).

Table 1. Geochemical Analysis of the Cihara Granodiorite (analysis 6, 7, 8) and Volcanic Rocks of the Cikotok Formation (analysis 1 to 5) (Fe as FeO, volatile free, normalized to 100 %; major elements in wt %, trace and rare earth elements in ppm)

Anal. no.	1	2	3	4	5	6	7	8
Name	Basalt	Basaltic andesite	Andesite	Q-Diorite	Dacite	Dacite	Granodiorite	Granite
Major elements								
SiO_2	50.90	53.44	59.00	59.08	61.90	63.74	67.38	75.65
TiO_2	0.81	0.85	0.49	0.86	0.61	0.38	0.56	0.00
Al_2O_3	20.89	18.79	16.61	17.88	16.18	16.08	15.66	13.39
FeO	9.05	9.01	8.07	6.38	8.40	5.73	3.93	1.56
MnO	0.17	0.25	0.20	0.12	0.38	0.22	0.07	0.04
MgO	4.38	3.89	3.25	4.92	2.51	3.81	1.66	0.49
CaO	11.13	9.16	6.79	6.25	4.87	4.88	3.55	1.43
Na_2O	2.46	3.35	3.92	3.50	3.54	2.94	3.87	3.76
K_2O	0.35	0.76	1.20	0.67	1.30	1.89	3.10	3.52
P_2O_5	0.26	0.50	0.47	0.35	0.42	0.34	0.21	0.17
Total	99.99	100.00	100.00	100.00	100.00	100.01	100.00	100.01
Trace elements								
Ba		130		195			213	221
Rb		21		16			42	44
Th		3		4			4	5
Nb		7		4			3	5
La		10		10			10	9
Ce							22	
Sr		347		243		303	77	173
Nd		6		7			9	5
Sm		3		3			2	2
Zr		102		157		119	< 0.01	45
Y		20		22			11	13
Yb		2		2			1	2
Sc		20		13				2
V		169		113				6
Cr		221		96		172		146
Ni		17		4		39		
Rare earth elements								
La	0.33	9.71		10.35			10.13	9.33
Ce	0.87	21.81		25.05			21.71	22.34
Pr	0.12	2.79		3.10			1.98	2.59
Nd	0.63	6.46		7.20			8.98	5.28
Sm	0.20	3.00		3.44			2.01	2.18
Eu	0.08	0.99		1.08			0.01	0.27
Gd	0.28	3.50		3.92			1.50	2.24
Dy	0.34	3.36		3.93			1.87	2.22
Er	0.21	2.12		2.58			0.61	1.50
Yb	0.21	1.93		2.48			0.74	1.69

In contrast, the abundance of LILE in Cihara Granodiorite is comparable with the abundance in OIB, but the HFSE concentrations of the Cihara rocks are lower.

The presence of hornblende and magnetite as well as the absence of ilmenite combined with geochemical data, such as low K_2O/Na_2O (0.2 – 0.9 wt %), medium Rb concentration (42 – 44 wt %), the SiO_2 content (55 – 74 wt %), and metaluminous-peraluminous series, suggest I-type granitic rocks (White and Chappel, 1977; Clarke, 1992). The rocks contain anorthite in the norm, varying from 6 to 29 % (Table 4.2 of Ardiansyah, 2007).

Two samples were analyzed for rare earth ele-
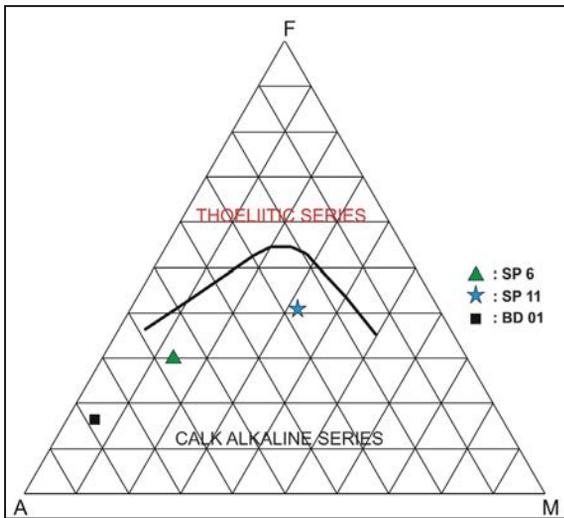
Figure 6. AMF diagram for the Cihara Granodiorite. The boundary between tholeiitic and calc-alkaline field is taken from Irvine and Baragar (1971).
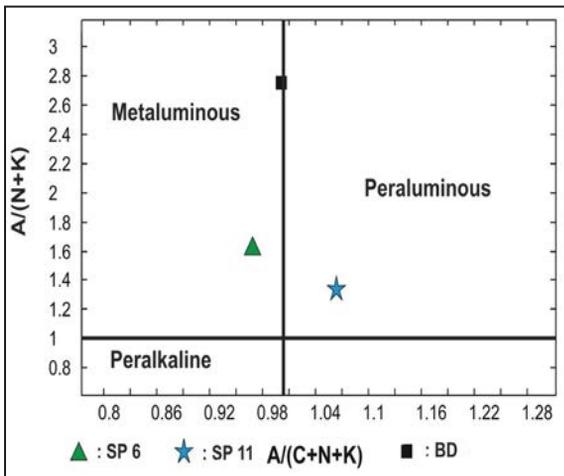
Figure 7. Classification of the Cihara Granodiorite based on aluminum-alkaline ratios (Maniar and Piccoli, 1989).

ments (REE) and the result is presented in Figure 10, which shows a moderate slope of the REE pattern. A negative Eu anomaly is a significant characteristic of the rocks.

DISCUSSIONS

The calc-alkaline series of the Cihara Granodiorite are indicative of a subducted related magmatism. As it is generally known that the calc-alkaline
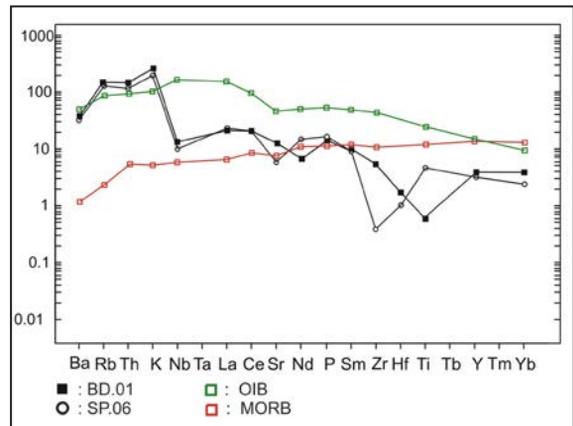
Figure 8. Chondrite-normalized trace element spidergram of the Cihara Granodiorite.

rocks are the only rock type found in a subduction zone, but not in other tectonic settings. The trace element data of the Cihara Granodiorite (Figure 8) also characterize the rock originated from a subducted related magma. The LILE (Ba, Rb, Th, K) abundance of the Cihara rocks are higher compared to that of MORB, but comparable to that of OIB. In contrast, the HFSE (Nb, Zr, Ti) concentrations of the Cihara Granodiorite are similar to that of MORB, but lower than that of OIB. The depletion of Nb relative to K and La is a significant characteristic of the subducted related magmatism. Like most of subduction related magma, these geochemical characteristics suggest that the Cihara Granodiorite magma may be derived from basaltic parent magma (by process of differentiation) originated in the mantle wedge above the slab that has been enriched by LILE. As the oceanic crust subducted beneath the other crust, it would release water and other incompatible elements (Ba, Rb, Th, and K). These elements would then be transported to the mantle wedge above the slab causing the enrichment of this depleted mantle. However, the proportion abundance of TiO_2, K_2O, and P_2O_5 (Figure 9) is not consistent with mantle melting magmas, but more likely came from magma of crustal origin. The metaluminous-peraluminous characters (Figure 7) of the Cihara Granodiorite magma may also indicate crustal magma sources, as crustal rocks are rich in aluminum content. The high content of Al_2O_3 (> 15%) and Sr (> 173 ppm) and low concentration of Y (≤3 ppm) and Yb (≤2 ppm) of the Cihara Granodiorite (Table 1) also suggest the
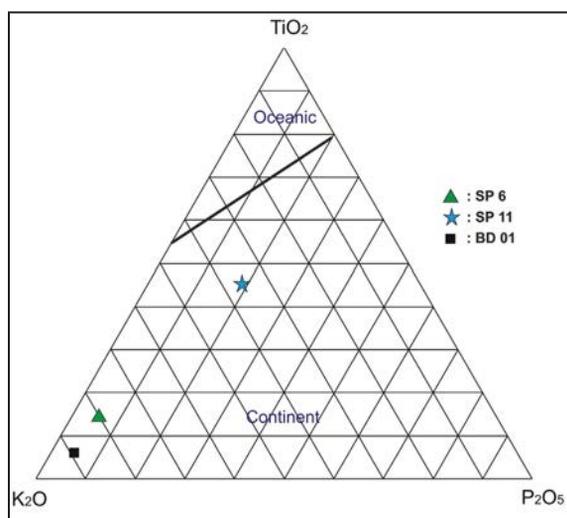
Figure 9. Identification of magmatic sources based on K_2O, TiO_2, and P_2O_5 concentrations (Pearce *et al.*, 1984) of the Cihara Granodiorite.

Figure 10. Chondrite-normalized rare earth element spidergram of the Cihara Granodiorite

rock was originated from a crustal melting magma. However, detailed observation on petrographical and geochemical data as well as considering its relationship to volcanic rocks of the Cikotok Formation suggest a more complex process in the generation of the magma. The process may include fractionation from a more basic parent magma of crustal origin (?) and magma mixing.

The moderate slope of the REE pattern and significant Eu negative anomalies (Figure 10) suggest the Cihara Granodiorite was a result of fractionation involving hornblende and plagioclase. Petrographic data, *i.e.*, the presence of plagioclase and hornblende phenocrysts in a significant amount (15 to 60 % and 3 to 7 % respectively: Ardiansyah, 2007), may support this interpretation. It is possible that the basaltic or andesitic magma (Hartono, in prep.) of the Cikotok Formation could be the magma parental to the granodiorite magma in the Bayah area. The quartz diorite (Table 1, analysis 6) with high Al_2O_3 (17.38 %) and Sr (303 ppm) concentrations could suggest the rock was originated from crustal melting magma, but it needs other trace element data, for example heavy rare earth elements (Y, Yb), to have a confident interpretation. Unfortunately, these data are not available because of a technical error during analysis. Alternatively, the high concentration of Al_2O_3 and Sr may be caused by a high content of plagioclase phenocrysts in the rock (up to 50%:

Ardiansyah, 2007).

Stratigraphic evidence, *i.e.* the unconformity between the Late Eocene Cicarucup Formation and the Sandstone Member of the Cijengkol Formations (Sujatmiko and Santosa, 1991) indicates the tectonic event occurred this time. This maybe the first tectonic event as suggested by Van Bemmelen (1949) as the Late Paleogene tectonic or pre-Pliocene tectonic by Koolhoven (1933), which caused uplifting, folding and faulting of the Eocene to Miocene rock formations. Van Bemmelen (*op. cit.*) suggested that this tectonic event possibly cause the initiation of the Bayah Dome. The Late Paleogene tectonic might have been caused by a subduction process (Hamilton, 1979) that resulted in arc characters of volcanic rocks (Hartono, in prep.) of the Cikotok Formation. As suggested by van Bemmelen (1949) and based on the stratigraphic position (Sujatmiko and Santosa, 1992) as well as considering the age (Koolhoven, 1933) the Cihara Granodiorite was formed relatively at the same time with the volcanic activity. Hence, based on this knowledge, it is possible that the Cihara Granodiorite is comagmatic with magma which produced the Cikotok Formation, and might have been a result of fractionation from the more basic arc magma of this formation.

To prove that hypothesis, the major element data of the Cihara Granodiorite are plotted together with the volcanic rocks of the Cikotok Formation in a Harker diagram (Figure 11). The figure shows that the Cihara Granodiorite data are, in general, sitting on the basalt-andesite-dacite Cikotok Formation

line for most of the major element data, indicating a genetic relationship between these two groups of rocks. The incompatible elements, K_2O and Na_2O are increased with increasing fractionation. The presence of plagioclase, hornblende, pyroxene, and magnetite phenocrysts in the Cihara Granodiorite is consistent with the distribution of the major element data in the Harker diagram, such as decreasing Al_2O_3, CaO, FeO, and TiO_2. Decreasing P_2O_5 might be caused by apatite fractionation, which presents as accessory minerals (Ardiansyah, 2007). If the interpretation is true, then the Cikotok Formation magma

should be originated from a continental crust source. Detailed discussion on the origin of magma of the Cikotok Formation will not be presented and beyond the scope of this paper. The following discussion deals with possible magma mixing involved in the generation of the Cihara Granodiorite to figure out its genetic relationship to the Cikotok magma.

Although it may not be a strong evidence, results of the petrographic analysis show the evidence of a more complex history in the magma generation of the Cihara Granodiorite, such as magma mixing. A possible magma mixing might play roles in the
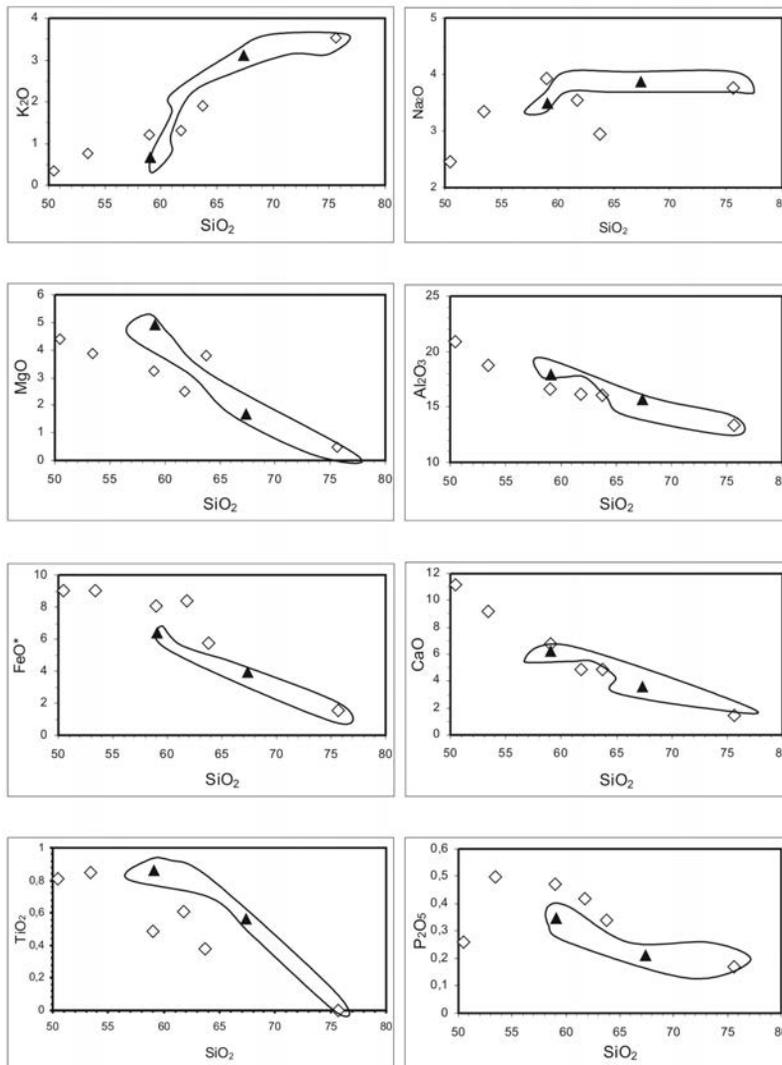
Figure 11. Major element Harker diagrams of the Cihara Granodiorite (within the area shown) plotted together with rocks from the Cikotok Formation.

generation of the Cihara Granodiorite. Petrographic data, such as the plagioclase resorpsions and quartz embayment (Figure 4), plagioclase reaction rims (Figure 3), and sieve texture (Figure 2) may be indicatives of the mixing. The presence of anorthite normative that varies from around 6 to 29 % in the Cihara Granodiorite (Ardiansyah, 2007) may also an evidence of magma mixing. Although the evidence is not strong enough, some degree of mixing may be involved in the fractionation processes. The mixing might involve two magmas of different sources and or compositions or simply a process suggested by O'Hara (1977) and O'Hara and Mathew (1981) *i.e.* a periodic replenishment, periodic tapping and continuous fractionation in the magma chamber. Due to limited data, it is difficult to explain the petrogenesis of the Cihara Granodiorite based on the mixing process, but a speculative interpretation might be suggested.

If the Cihara Granodiorite magma was originated from basaltic/andesitic magma from the Cikotok Formation by a process of fractional crystallization differentiation as discussed before, then the mixing process suggested by O'Hara (1977) and O'Hara and Mathew (1981) might be proposed. A periodic replenishment and periodic tapping during continuous fractionation in the magma chamber by new basaltic/or andesitic magma of the Cikotok Formation would result in a geochemical variation of the Cihara Granodiorite rocks. The mixing was involving two magmas of different compositions, but similar source. Alternatively, in the case of the first mixing mechanism, *i.e.*, mixing of two magmas of different sources and compositions, it is possible that the Cihara Granodiorite parent magma might have been produced by mixing of magma originated from melting of the Java crust and subducted related magma (either mantle or slab melting origin). Subduction of the Indian oceanic crust beneath Jawa in the Late Paleogene (Hamilton, 1979) would cause melting of either the mantle wedge above the slab or the down going slab producing a basaltic magma. Heating of the Jawa lower crust by this basaltic magma could have caused melting to produce intermediate parent magma of the Cihara Granodiorite similar composition to the quartz diorite (Table 1, analyses 8). Fractional crystallization involving plagioclase, hornblende, pyroxene, and magnetite

of this parent magma would produce geochemical variation of the Cihara Granodiorite. This process is simultaneous with a periodical replenishment and tapping of the magma chamber by the new basaltic magma of the subduction related origin.

CONCLUSIONS

Petrographic and geochemical characteristics of the Cihara Granodiorite suggest that this rock was originated from subducted related magma of a crustal origin. Fractional crystallization involving plagioclase, hornblende, pyroxene, and magnetite might produce geochemical variation of the Cihara Granodiorite. It is still open for discussing the parent magma, either the basaltic or andesitic magma of the Cikotok Formation or an intermediate magma resulted from Jawa lower crust melting. If the Cihara Granodiorite magma is a differentiated product of the basaltic/ or andesitic magma of the Cikotok Formation, then the Cikotok magma have to be originated from a crustal source or sources. More data, for example some trace elements, of the Cikotok rocks are needed to make a conclusion that the Cikotok basalt is originated from crustal sources. A more speculative interpretation is that, the Late Paleogene subduction of the Indian oceanic crust beneath the Jawa continent caused melting of either the mantle wedge above the slab or down going slab. This magma then heated the Jawa crust on rising to the surface and caused crustal melting, producing intermediate magma of the Cihara Granodiorite. Fractional crystallization of this parental magma involving plagioclase, hornblende, pyroxene, and magnetite may produce geochemical variation of the Cihara Granodiorite. Although the magma of crustal origin might be the dominant component that resulted in the Cihara Granodiorite, petrographical and geochemical data indicate some degree of mixing involved in the generation of magma. The mixing process could happen in the magma chamber by replenishment of a subducted related new basaltic magma of either mantle or slab melting.

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