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Petrology and Geochemistry of Microgabbro in Watugajah Area, Gedangsari, Southern Mountains

Petrologi dan Geokimia Mikrogabro di Daerah Watugajah, Gedangsari, Pegunungan Selatan

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Abstract-An intrusive igneous rock with a columnar joint structure having a height of approximately 55 m cropped out in the Watugajah area, Gedangsari, Gunung Kidul Regency, Yogyakarta Special Province. This region geologically is in the western part of the Southern Mountains, part of the Baturagung Subzone, which belongs to the Kebo Formation. This study aims to characterize the igneous rock in the Watugajah area of the Southern Mountains. It suggests the petrogenetic information of this igneous rock and gives a new consideration of the geological history in the Kebo Formation.

Geological field mapping was managed in the research area to identify the correlation with other rock units. Rock samples were collected to characterize their composition by petrographical and geochemical analyses. The results suggest the igneous rocks intruded sedimentary rocks of the Kebo Formation, which consists of intercalations coarse sandstone and tuff, fine sandstone and siltstone, and tuff and fine sandstone units. The igneous rocks are classified as microgabbro and basalt in the form of the sill and dyke intrusions. The microgabbro and basalt consist of plagioclase, clinopyroxene, and magnetite, formed by the cooling of magma in the shallow depths. Based on geochemical studies, the igneous rocks of the Watugajah area were formed by subduction zone tectonic setting with the tholeiitic affinity.

Keywords: Gedangsari, microgabbro, Southern Mountains, subduction, Watugajah.

Abstrak-*Tubuh intrusi batuan beku dengan struktur kekar tiang memiliki tinggi sekitar 55 m tersingkap di Daerah Watugajah, Gedangsari, Kabupaten Gunungkidul, Daerah Istimewa Yogyakarta. Lokasi tersingkapnya tubuh intrusi tersebut secara geologi merupakan bagian dari Pegunungan Selatan bagian barat, tepatnya pada Subzona Baturagung, yang termasuk ke dalam Formasi Kebo. Studi ini ditujukan untuk mengetahui karakteristik tubuh intrusi batuan beku tersebut. Informasi petrogenesis batuan beku tersebut merupakan parameter baru untuk menjelaskan sejarah geologi Formasi Kebo di Pegunungan Selatan.*

Penelitian dilakukan melalui pemetaan geologi di daerah penelitian untuk mengidentifikasi kehadiran intrusi batuan beku tersebut dan dikorelasikan dengan satuan batuan lain. Selanjutnya dilakukan pengambilan sampel batuan untuk mengetahui komposisi secara petrografi dan geokimia. Hasil analisis menunjukkan bahwa intrusi batuan beku menerobos batuan sedimen dari Formasi Kebo yang tersusun atas satuan perselingan batupasir kasar dan tuff, satuan perselingan batupasir halus dan batulanau, dan satuan perselingan tuff dan batupasir halus. Intrusi batuan beku berupa sill dan dike, dan diklasifikasikan sebagai mikrogabro dan basalt. Mikrogabro dan basalt tersusun atas mineral utama berupa plagioklas, klinopiroksen, dan magnetit yang terbentuk dari pembekuan magma pada kedalaman dangkal. Berdasarkan studi geokimia, batuan beku di Daerah Watugajah terbentuk pada seting tektonik zona subduksi dengan afinitas magma tholeiitic.

Katakunci: *Gedangsari, mikrogabro, Pegunungan Selatan, subduksi, Watugajah.*

INTRODUCTION

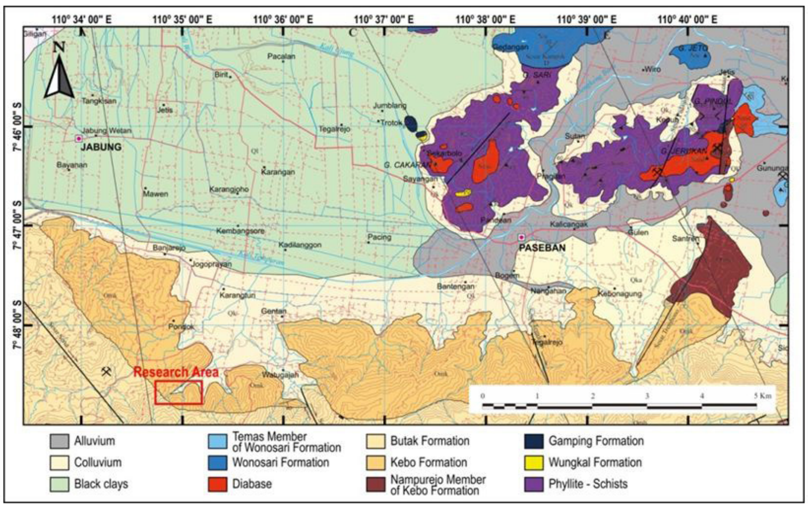
The Kebo Formation in the Southern Mountains consists of volcaniclastic sedimentary rocks, which are intercalation of sandstone and gravelly sandstone with an interlayer of siltstone, claystone, and tuff (Surono, 2008). Geologically, this region is in the western part of the Southern Mountains, part of the Baturagung Subzone (van Bemmelen, 1949), which belongs to the Kebo Formation (Barianto *et al.*, 2017). There are several igneous rocks as a member of this formation. Those are volcanic rocks, fragments in the sedimentary rocks, and minor intrusive rocks. The most significant volcanic rock member of the Kebo Formation is basaltic pillow lava of Nampurejo Member, which is located in the eastern side of the Kebo Formation (Barianto *et al.*, 2017; Surono, 2008; Figure 1). Some research had been done in the basaltic pillow lava of the Nampurejo Member that showed their general composition, stratigraphic correlation, and their possibility of magmatic correlation with igneous rocks in the Jiwo Hills (Bronto *et al.*, 2004; Hirawan et al., 2017; Surono, 2008).

The occurrence of the intrusive igneous rock in the western side of the Kebo Formation might give a new insight into this formation. This research aims to characterize the igneous rock in the Watugajah area of the Southern Mountains region by its occurrence, petrological, and geochemical analyses. The results provide petrogenetic information of the igneous rock in the Watugajah area and a new consideration of the geological history in the Kebo Formation.

GEOLOGICAL BACKGROUND

The Kebo Formation considerably consists of volcaniclastic sedimentary rocks, with a total thickness of 650 m, and extends approximately 20 km E–W in the Southern Mountains, the southern part of Jiwo Hills (Mulyaningsih, 2016; Sumarso & Ismoyowati, 1975; Surono, 2008; Figure 1). This formation is bounded in the bottom and top with Wungkal-Gamping and Butak Formations, respectively (Barianto *et al.*, 2017). The Wungkal-Gamping Formation generally consists of nummulitic limestone, sandstone, sandy marl, and claystone (Surono, 2008). However, the direct contact of this formation with the Kebo Formation has never been found (Husein & Sari, 2011; Surono, 2008). Meanwhile, the Butak Formation mainly consists of polymict breccia intercalation with sandstone, gravelly sandstone, claystone, and siltstone (Surono, 2008).

The lower part of the Kebo Formation consists of sandstone, gravelly sandstone, siltstone, claystone, tuff, and shale. The middle part consists of pebbly sandstone, while the upper part consists of polymict breccia, sandstone, pebbly sandstone, claystone, and shale (Husein & Sari, 2011; Surono, 2008). Furthermore, the Nampurejo Member, which consists of intercalation of basaltic pillow lava and dark volcanic sandstone, is suggested as the sole of this formation (Surono, 2008). The age of this formation is suggested from Late Oligocene to Early Miocene based on their faunal composition and radiometric dating analyses (Rahardjo, 2007; Sumarso & Ismoyowati, 1975; Surono et al., 2006). During the deposition of the Kebo-Butak Formation, magmatic activities took place, possibly in a submarine volcanic setting, as suggested by some fragments of basaltic pillow lava (Husein & Sari, 2011; Sumarso & Ismoyowati, 1975).



source: *Modified Barianto et al., (2017)*

Figure 1. Geological map of the Southern Mountains and the Jiwo Hills. The research area is in the Kebo Formation.

METHODS AND MATERIALS

Geological field mapping was managed in the research area to identify the correlation with other rock units. Forty-five geological field stations were obtained to collect the geological data and rock samples. Selected rock samples were thin-sectioned for petrographical analysis. Furthermore, the selected least altered igneous rocks were analyzed whole-rock chemistry at the commercial laboratory of ALS Mineral, Vancouver, Canada, with modes of ME-MS81D. This laboratory used the geochemical of ICP-AES and ICP-MS methods to obtain major elements and trace- and rare-earth elements, respectively.

RESULTS AND DISCUSSION

Field Investigation

The Watugajah area comprises volcaniclastic sedimentary and igneous rocks based on the geological mapping results. The general trend of the sedimentary stratification is NW-SE with the dip of 11–22º to SW. The oldest to youngest sedimentary units in this area are intercalations of coarse sandstone and tuff, fine sandstone and siltstone, and tuff and fine sandstone units (Figure 2) with contact lithology of normal gradation.

The Sampang River was interpreted as a sinistral strike-slip fault with NE-SW trend by its geometry and offset in the intercalation of coarse sandstone and tuff unit. The fault formed as a permeable zone, which intruded by several fine dykes. The igneous rocks in this area are microgabbro and basalt as sill and dyke intrusions. The main intrusion body in the Watugajah area is a sill intrusion. The sill intruded concordantly in the intercalations of coarse sandstone and tuff and fine sandstone units. Meanwhile, the dyke is exposed along the Sampang River with minor sizes (Figure 2).

The major outcrop of the sill is approximately having 55 m in thickness, which is located in the abandoned quarry area. A local normal fault was identified to cut the sill. The direction of the fault is N145ºE/19º with the rake of slickenside is 78º S. Furthermore, the columnar joints are made by the mechanical strength of magma during cooling and contracting, which creates tensional stresses within the body (Hetényi *et al.,* 2012). Fractures will initiate perpendicularly to the isotensile-stress surface, often identical to an isothermal surface, i.e., parallel to the cooling surface (Spry, 1962). The columnar joints direction are 74–76º heading to NW, which represent perpendicular to the geometry of the sill (Figure 3a).

The sill has columnar joint structures dominated by pentagonal and tetragonal shapes with a minor hexagonal shape (Kurniawati *et al.,* 2017). The average column's width is approximately 1 m (Figure 3b). The width of each column is related to the cooling rate and viscosity of the magmas. Slower cooling rate and more viscous magmas would generate a wider column (Hetényi *et al*., 2012). The number of polygons in each columnar joint is also related to the magma's cooling rate. The highest cooling rate would decrease the number of polygons in the columnar joints (Toramaru & Matsumoto, 2004). Therefore, based on the column's width and polygon shapes, the magma related to the columnar joints in this area are moderately cooling rate and viscous magma, which is ideal for the shallow intrusion setting.

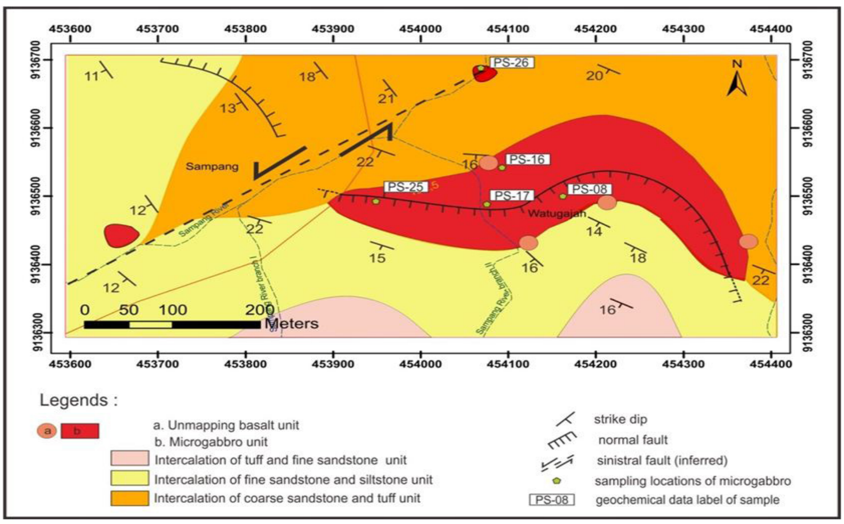


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Figure 2. Geological map of the study area in the Watugajah, Gedangsari, and sample locations (modified from Kurniawati, 2017). The map coordinate is generated from the Geospatial Information Agency of Indonesia (BIG)

The sedimentary rocks in contact with the intrusion exhibit to be more compact and have conchoidal textures, considered as baked margins (Figure 3c). The basalts, more fine-grain crystal sizes found in the margin of the intrusion with the country rocks are interpreted as chilled margin (Figure 3d).

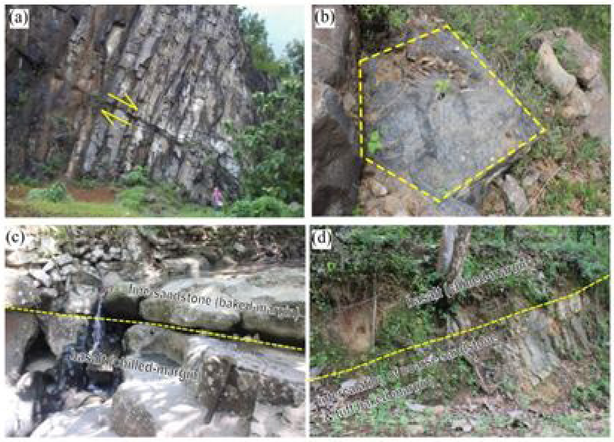

Figure 3. Modes of occurrence microgabbro intrusions in the Watugajah area. (a) Body of sill with the thrust fault and columnar joints. (b) The pentagonal structure of columnar joint with the average 1 m width. (c) and (d) Contact lithology shows baked- and chilled margins of basalt and the country rocks.

Petrographical Analysis

There were 14 thin sections observed under the polarization microscope, of which 10 were derived from the sill and 4 from the dike intrusions. The summary of the petrographical observation is shown in Table 1.

Generally, most of the rock samples were slightly altered. It is shown by the appearance of secondary minerals chlorite, quartz, and clay minerals (Table 1). Based on the crystal size, the igneous rocks can be divided into 2 groups: coarse-grain (0.5–2 mm) and fine-grain (0.1–0.6 mm). The coarse-grain crystal size rocks have phaneritic, intersertal, and subophitic textures. Furthermore, the rock consists of plagioclase (60–75 %) and clinopyroxene (12–18 %) with a minor accessory mineral of magnetite (5–15 %). The secondary minerals observed in the rocks are chlorite (2–10 %), with calcite, quartz, and clay minerals are occasionally occur (Figure 4a–d). The plagioclase is qualitatively classified as labradorite from their extinction angle (28–32º). The petrographical analysis reveals that the coarse-grain igneous rocks are classified as microgabbro based on classification from Streckeisen (1974). Meanwhile, the fine-grain crystal size rocks have aphanitic and intersertal textures. It consists of plagioclase, clinopyroxene, and magnetite, classified as basalt (Figure 4e–f).

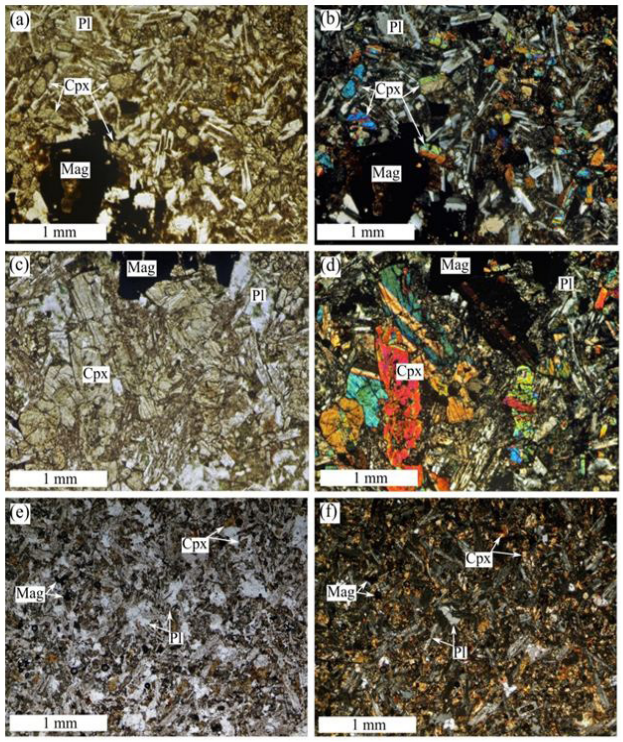

Figure 4. Photomicrograph of igneous rocks in the Watugajah area. The left and right sides are PPL and XPL images, respectively. (a)–(d) are photomicrographs of microgabbro, which consists of plagioclase (Pl) and clinopyroxene (Cpx) as primary minerals, and magnetite (Mag) as an accessory mineral. (e) and (f) are photomicrographs of basalt, which consists of plagioclase (Pl), clinopyroxene (Cpx), and subordinate magnetite (Mag).

Geochemical Analysis

We selected the least altered rock samples for the geochemical analysis based on the hand specimen and petrographical analyses. Totally 5 samples were selected, which 4 samples of the sill, and 1 sample of the dyke, representing the intrusion in the Watugajah area. The geochemical data are presented in Table 2.

The geochemical classification of plutonic rock based on Total Alkali-Silica (TAS) Na_2O+K_2O *vs.* SiO_2 diagram (Cox et al., 1979) confirmed all samples are classified as gabbro (Figure 5a). The rocks have narrow SiO_2 (52.00–52.70 wt.%), K_2O (0.78–1.20 wt.%), and Na_2O (2.86–3.27 wt.%) compositions. The AFM diagram (Irvine & Baragar, 1971) shows that the microgabbro has a tholeiitic affinity. It shows the increase of FeO_{Total} (Figure 5b), which might be indicated the undifferentiated magma. Furthermore, the rocks are plotted in the discrimination diagram of Y *vs.* Cr (Pearce, 1982), which clustering in the border of volcanic arc basalt (VAB), within-plate basalt (WPB), and mid-oceanic ridge basalt (MORB) (Figure 5c). Much lower yttrium content in the igneous rock is considered volcanic arc-related (Pearce, 1982). The microgabbro samples are plotted on the

Ta-Hf-Ta discrimination diagram (Wood, 1980), which is consistently located in the area of volcanic arc basalt (VAB) tectonic environment (Figure 5d). Furthermore, the number of V in the microgabbro is considerably high (374–551 ppm; Table 2) suggested by the abundant of magnetite in the rock samples (4.2–11.5 %; Table 1) as V is concentrated in the magnetite (Winter, 2013).

Table 1. Summary of petrographical analyses of igneous rock from the Watugajah area, Gedangsari

Sample No	Rock Name	Type of Intrusion	Mineral Composition (%)						
			Primary			Secondary			
			Pl	Cpx	Mag	Chl	Qz	Cal	Cly
PS-2	Basalt	Sill	84.4	8.5	2	5.1	-	-	-
PS-3	Microgabbro	Sill	74.8	15.2	9	1	-	-	-
PS-8*	Microgabbro	Sill	64.7	19.5	8.8	4	3	-	-
PS-9	Microgabbro	Sill	79.1	9.5	5.4	5	1	-	-
PS-16*	Microgabbro	Sill	70.6	16.2	11.2	2	-	-	-
PS-17*	Microgabbro	Sill	73.8	16.2	9	1	-	-	-
PS-18	Microgabbro	Sill	65.8	18.1	11.1	5	-	-	-
PS-19	Basalt	Sill	76.2	8	1	7.3	4.5	3	-
PS-24	Microgabbro	Sill	71.3	16.8	8.9	3	-	-	-
PS-25*	Microgabbro	Sill	75	9.8	8	7.2	-	-	-
PS-26*	Microgabbro	Dyke	79.4	9.4	4.2	7	-	-	-
PS-31a	Basalt	Dyke	78.5	2	2	17.5	-	-	-
PS-31b	Basalt	Dyke	43	4	21	-	-	-	32
PS-34	Microgabbro	Dyke	62.6	17.6	11.5	6.3	2	-	-

Mineral abbreviation: Pl (plagioclase), Cpx (clinopyroxene), Mag (magnetite), Chl (chlorite), Qz (quartz), Cal (calcite), and Cly (clay minerals)

**) Rock samples used for geochemical analysis*

Table 2. Geochemical results of ICP-AES/MS of microgabbro from the Watugajah area

Oxide/ Element	Unit	PS-08	PS-16	PS-17	PS-25	PS-26
SiO_2	%	52.70	52.30	52.00	52.20	52.00
Al_2O_3	%	14.80	14.80	14.20	14.90	14.60
Fe_2O_3	%	12.10	11.45	12.55	12.30	11.15
CaO	%	7.86	8.23	8.62	7.76	7.78
MgO	%	4.66	5.32	6.21	4.25	5.29
Na_2O	%	3.27	3.06	2.86	3.05	3.09
K_2O	%	0.96	0.84	0.78	1.20	0.86
Cr_2O_3	%	0.01	0.01	0.02	0.01	0.01
TiO_2	%	1.34	1.12	1.24	1.42	1.14
MnO	%	0.21	0.19	0.23	0.20	0.24
P_2O_5	%	0.22	0.19	0.20	0.20	0.19
SrO	%	0.02	0.02	0.02	0.02	0.02
BaO	%	0.01	0.01	0.01	0.01	0.01
LOI	%	3.05	2.92	3.03	3.35	4.09
Total	%	101.21	100.46	101.97	100.87	100.47
Ba	ppm	100.50	90.90	81.60	136.50	80.00
Ce	ppm	16.00	15.10	16.10	16.40	15.20
Cr	ppm	50.00	100.00	110.00	40.00	90.00
Cs	ppm	0.19	0.40	0.21	0.39	0.51
Dy	ppm	5.56	5.05	4.99	5.22	5.19
Er	ppm	3.32	3.26	3.18	3.33	3.32
Eu	ppm	1.15	1.17	1.13	1.20	1.16
Ga	ppm	17.40	16.30	16.50	18.30	17.70
Gd	ppm	4.62	4.66	4.63	4.93	4.51
Hf	ppm	2.80	2.70	2.40	2.70	2.70
Ho	ppm	1.18	1.11	1.16	1.19	1.12
La	ppm	6.20	5.90	6.40	6.30	6.00
Lu	ppm	0.52	0.51	0.47	0.51	0.47
Nb	ppm	1.30	1.10	3.90	1.90	1.30
Nd	ppm	12.60	11.50	12.40	12.60	12.00
Pr	ppm	2.49	2.40	2.52	2.46	2.46
Rb	ppm	19.40	18.50	15.20	24.80	13.80
Sm	ppm	3.88	3.80	3.63	4.10	3.73
Sn	ppm	1.00	1.00	1.00	1.00	1.00
Sr	ppm	196.50	185.50	169.00	171.00	164.00
Ta	ppm	0.10	0.10	0.10	0.10	0.10
Tb	ppm	0.80	0.74	0.72	0.78	0.80
Th	ppm	1.37	1.21	1.21	1.27	1.23
Tm	ppm	0.47	0.47	0.45	0.48	0.45
U	ppm	0.41	0.39	0.36	0.62	0.39
V	ppm	469.00	374.00	451.00	551.00	404.00
W	ppm	<1	<1	<1	<1	<1
Y	ppm	30.60	28.80	28.20	30.50	29.20
Yb	ppm	3.44	3.23	3.01	3.10	3.06
Zr	ppm	95.00	89.00	83.00	93.00	87.00

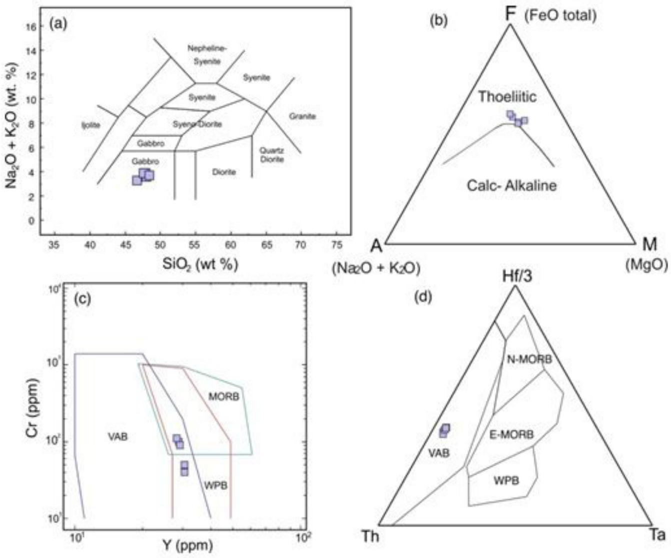

Figure 5. Geochemical discrimination diagram of microgabbro from the Watugajah area. (a) TAS diagram (Cox *et al.*, 1979) (b) AFM diagram (Irvine and Baragar, 1971), (c) Cr vs. Y (Pearce, 1982), and (d) Th-Hf-Ta diagram (Wood, 1980).

The trace element data is summarized in a spider diagram using C1 chondrite normalization (McDonough & Sun, 1995; Figure 6a). The averages of E-MORB, N-MORB, and OIB based on Sun & McDonough (1989) are shown in the diagram for comparison. The pattern shows enrichment of large-ion lithophile elements (LILE) of Rb and Ba compared to high-field strength elements (HFSE), e.g., Ta–Yb. The LILE enrichment is typical for subduction zone magma, which is rich in hydrous fluid components. The slightly flat HFSE similar to the N-MORB pattern might be indicated the magma less differentiated or fractionated (Winter, 2013). It might be derived from the depleted mantle or relatively young and hot subducting crust.

The negative Nb, Ta, and Ti anomalies might be related to the absence of residual Nb-Ta-Ti-bearing minerals, e.g., rutile, ilmenite, sphene, and hornblende (Rollinson, 1993). The negative Nb anomaly is also characteristic of the continental crust and may indicate crustal involvement in magma processes (Rollinson, 1993). Furthermore, the negative anomaly of Nb is also related to the fractionation of its from Th and Ce elements during dehydration on the partial melting of the subducting crust. The Th and Ce elements mobile from the subducting crust to the melt in the mantle wedge, while Nb concentrates in the mineral phase of amphibole, titanite, and rutile in the subducting crust (Pearce, 1996).

The REE pattern shows slightly enriched of light rare-earth elements (LREE), e.g., La, Ce, Pr, Nd, and Sm relatively to heavy rare-earth elements (HREE) of Tb, Dy, Ho, Er, Tm, Yb, and Lu (Figure 6b). The slight enrichment of LREE might be caused by the presence of mafic minerals (clinopyroxene) in these samples of its high partition coefficients of these elements (Rollinson, 1993). All samples have a negative anomaly of Eu. The negative anomaly of Eu is controlled by plagioclase was an important fractionating phase from the melt in the microgabbro formation (Rollinson, 1993). The plagioclase has a high distribution coefficient of Eu, which might be retained in the source of microgabbro; hence the extracted melt is depleted in Eu. Meanwhile, the HREE shows relatively flat, which imply garnet was not in equilibrium the melt at the time of segregation. This suggests the rocks are not related by deep fractionation processes (Winter, 2013).

Magmatism in the Kebo Formation

The Kebo Formation is considered dominantly consists of volcaniclastic rocks (Mulyaningsih, 2016; Sumarso & Ismoyowati, 1975; Surono, 2008). The magmatic activities took place during the deposition, possibly in a submarine volcanic setting, as suggested by some fragments of basaltic pillow lava (Surono, 2008). This lava could be found in Nampurejo, Kalinampu, Santren, and Tegalrejo areas (Bronto *et al.*, 2004; Hirawan et al., 2017; Surono *et al.*, 2006), which suggested as the sole of the Kebo Formation (Surono, 2008). Furthermore, this extrusive igneous rock was classified as a Nampurejo Member of the Kebo Formation (Barianto *et al.*, 2017). The radiometric ages of these igneous rocks in these areas yielded 24.25 ± 0.65 Ma in the Tegalrejo area (K-Ar;

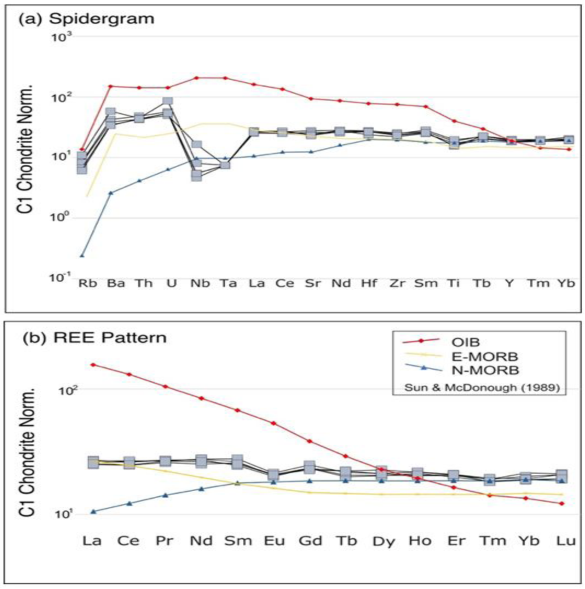

Figure 6. Chondrite-normalization (McDonough & Sun, 1995) (a) spider diagram and (b) REE pattern of microgabbro from the Watugajah area.

Soeria-Atmadja et al., 1994), 24.7 ± 1.0 Ma in the Santren area (U-Pb SHRIMP; Smyth, 2005 in Surono, 2008), 29.0 ± 1.4 in the Kebo-Butak Fm. (?) (U-Pb SHRIMP; Smyth, 2005 in Mulyaningsih, 2016), and 30.04 ± 4.62 Ma in the Cermo area (K-Ar; Surono et al., 2006). Those ages are younger compared to the igneous rocks of Pendul intrusion from the Jiwo Hills, which are 31 to 39 Ma (K-Ar; Soeria-Atmadja et al., 1994; Sutanto et al., 1994).

The subduction-related magmatism in the Java Island during the Paleogene Period was suggested responsible for igneous rocks in Jiwo Hills and Southern Mountains, known as the Old Andesite Formation (Setijadji *et al.,* 2006; van Bemmelen, 1949). Many publications considered that the magmatism in the Jiwo Hills might be correlated with the Southern Mountains. The igneous rocks of the Jiwo Hills and the Nampurejo Member of the Kebo Formation were proposed cogenetic magmatism from their similarity of composition and geochemical signature (Bronto *et al*., 2004; Hirawan *et a*l., 2017; Surono *et al.*, 2006). The basaltic pillow lava of the the Nampurejo Member was suggested as a subaqueous volcanic product from the single magmatic process with the Jiwo Hills (Bronto *et al.*, 2004). Furthermore, it is also suggested that the intrusive igneous rocks in the Jiwo Hills as a conduit pipe or lava dome with several parasitic cones occupied in the Gunung Sepikul and Cermo areas (Bronto et al., 2004). The age differences between these areas were considered due to the gab magmatic differentiation and fractionation processes (Hirawan et al., 2017; Surono et al., 2006).

This study reveals the microgabbro in the Watugajah area, Gedangsari intruded the Kebo Formation, which consists of intercalations of coarse sandstone and tuff, fine sandstone and siltstone, and tuff and fine sandstone units (Figures 2 & 3). Based on the stratigraphic correlation as provided by Surono (2008), it is concluded that the intrusion of the microgabbro is younger than the basaltic pillow lava of the Nampurejo Member. However, Husein & Sari (2011) suggested that the basaltic pillow lava of the Nampurejo Member in the Mojosari Area is possible as an allochthon unit in the Kebo Formation. This conclusion was based on the clustered distribution of the pillow lava surrounded by highly deformed volcaniclastics of the Kebo Formation. Furthermore, they also identified the intrusive igneous rocks within the Kebo Formation in their study area (Husein & Sari, 2011).

Although our geochemical signature of the microgabbro in the Watugajah area is similar to the characteristics of the igneous rocks from the Nampurejo Member and the Jiwo Hills, which is subduction-related (e.g., Bronto *et al.*, 2004; Hirawan et al., 2017; Surono et al., 2006; Sutarto *et al*., 2020; Figures 5 & 6), the magmatic association between these areas need to be reviewed. Further research and analyses are needed to define this matter. This research still needs to be developed in some aspects, e.g., comparing the composition, geochemical data (including isotopes), and more data of absolute dating in the igneous rocks.

CONCLUSIONS

The igneous rocks in the Watugajah area, Gedangsari, with the columnar joints, are classified as microgabbro and basalt in the form of the sill and dyke intrusions. The sill and dyke intruded sedimentary rocks of the Kebo Formation, which consists of intercalations of coarse sandstone and tuff, fine sandstone and siltstone, and tuff and fine sandstone units. The microgabbro and basalt dominantly consist of plagioclase, clinopyroxene, and magnetite formed by the cooling of magma in the shallow depths. Based on geochemical data, the igneous rocks of the Watugajah area formed by subduction zone tectonic setting of Indo-Australian below Eurasian plates with the tholeiitic affinity.

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