A preliminary study of geology and skarn of Cemorosewu Area, Bayat, Central Java, Indonesia

W N Muhammad¹, N I Setiawan¹*, S Husein¹, M Nukman²

¹Geological Engineering Department, Engineering Faculty, Universitas Gadjah Mada, Yogyakarta, Indonesia
²Geophysics Department, Mathematics and Natural Sciences Faculty, Universitas Gadjah Mada, Yogyakarta, Indonesia

*E-mail: nugroho.setiawan@ugm.ac.id

Abstract. We present the first finding of skarn rocks in Cemorosewu area of East Jiwo Hill, Bayat, Central Java, Indonesia. The geological conditions of this area which related to the appearance of the skarn is also reported. The methods used in this research are DEM acquisition using drone to generate basemap for geological mapping and thin section petrographic analyses. The geological map shows that Cemorosewu area consists of metamorphic rocks (mica phyllite, graphite phyllite, with quartzite and marble lenses), sedimentary rocks (carbonate breccia and siltstone), and igneous rock (microdiorite). Based on the field observation and geological map, the regional metamorphic rocks are the oldest units in this area followed by sedimentary rocks and igneous rock which intruded both rocks. Skarn rocks were cropped out as a boulder along the Kluwihan creek with the maximum size of 8 m in length. The skarn consists of garnet, clinopyroxene, zoisite, actinolite, and minor quartz. Metasiltstone and skarn rock are suggested formed by contact metamorphism of microdiorite intrusion. The marble, which lenses within the phyllites, is suggested to be the protolith of the skarn formation in this area.

1. Introduction

Jiwo Hills in Bayat is well known for the occurrences of regional metamorphic rocks in Central Java, Indonesia, together with Luk-Ulo Complex and Ciletuh Complex in West Java [1]. The regional metamorphic rocks are considered to be the oldest rocks in this area, which are unconformably overlain by Paleogene and Neogene sedimentary rocks, which were intruded by Oligo-Miocene igneous rocks [2]. Metasomatic skarn was reported in the Pagerjuran area of West Jiwo as a product of contact metamorphism between microgabbro and marble [1; 3] even though similar geological condition with the West Jiwo, the skarn in East Jiwo have never been reported.

Skarn rocks crop out as a boulder along the Kluwihan creek of Cemorosewu area with the maximum size of 8 m in length (Figures 1 and 2). The purpose of this study is to investigate the geological conditions of the Cemorosewu area, East Jiwo related to the first finding of the skarn rock, by geological mapping and petrographic analyses.
2. Regional Geology
Jiwo Hills in Bayat is one of the areas that crop out the basement rocks in Central Java, Indonesia [1]. The Jiwo Hills is divided into West and East Jiwo by NE–SW trend of Dengkeng River (Figure 1). The metamorphic rocks (phyllite, marble, and quartzite) are considered the basement rocks in these areas with the age of Early Cretaceous [2; 4]. The chrono-stratigraphic correlation suggested the regional metamorphic rocks unconformably overlain by Eocene sedimentary rocks of Wungkal and Gamping Formations (quartz sandstone and nummulitic limestone), Oligocene-Early Miocene volcaniclastic rocks of Kebo-Butak Formation, and intruded by Oligo-Miocene of dioritic to gabbroic igneous rocks [2; 4]. The carbonate rocks of the Wonosari Formation overlain the Kebo-Butak Formation in Middle-Late Miocene [2]. Furthermore, major faults found on the Jiwo Hills are showing four general orientations of NE–SW, N–S, NW–SE, and E–W [4].

3. Methodology
Detailed geological mapping was conducted in the Cemorosewu area of East Jiwo with the main target to understand the distribution of skarn rocks. The skarn rocks and the other lithology including igneous and sedimentary rocks, were collected and analyzed petrographically. Drone operation was conducted to the acquisition of elevation and imagery of the research area. The elevation data produced from drone operation is processed into a digital elevation model (DEM) to build the research base map of geological field mapping (Figure 2).
The surface geological mapping area is 284 x 272-m square area, which producing a geological map scale of 1: 1500 (Figures 2 and 3). This activity is carried out by directly observing the condition of geological objects of the outcrops in the research area. In total 21 field stations were used to record the geological conditions in this area (Figure 2). Twenty-one thin sections of rock samples were analyzed under the polarized-light microscope to determine the mineralogy and characteristics of rocks in the study area.

Figure 2. Observation stations of this study indicated by circles. The color of the circle denotes the lithology observed. Field photographs and thin section photos of some of the observation stations are shown on figures 4 and 5, respectively. The geological map is shown on figure 3. Station 6 is on the same location as station 5.

4. Geology of Cemorosewu area

The geological map, section and stratigraphic column resulted from this research is shown in figure 3. No major faults were recognized in this area, only 1 minor sinistral strike-slip fault recorded in the metasiltstone (Figures 3 and 4e). Based on the observed data from the field, there are 6 rock units observed in the field as follows from older to younger, respectively:

4.1. Phyllite with marble lenses unit

This unit covers about 50% of the study area. Based on the observation on station 15 (Figure 2) it has dark brown color with phyllitic structure, composed of platy minerals of mica. In several places, graphite phyllite rocks are found which dominated by graphites instead of micas. Both quartzite and marble lenses are common, marble lenses that are quite prominent are shown on the geological map. The field photograph and hand specimen are shown on figures 4a and 4h, respectively. The general foliation direction of this rock is N20°–60°E. Hydrothermal alteration processes are indicated by secondary quartz and hematite which found on a few places.
4.2. Carbonate breccia unit
This unit is found as an outcrop with dimensions of 4 m long and 3 m wide, surrounded by phyllite rocks. The outcrop is located on station 14 in figure 2. The photograph of the outcrop can be seen on figure 4b. It is difficult to determine whether the outcrop is a float or in-situ rock. However, observations elsewhere in East Jiwo outside the study area indicate that the carbonate breccia lies unconformably over the phyllite. The lithological description of the breccia is gray-colored, gravel grain size, poorly sorted, angular grain shape, closed fabric, massive structure, consisting of metamorphic rock fragments and a matrix composed of carbonate material.

4.3. Siltstone unit
This unit covers about 10% of the study area. The description of the rock is based on field observation of station 18 on figure 2, which is brownish-gray color, good sorting, closed fabric, silt grain size, consisting of siliciclastic material with silt size, and a small amount of ash-sized volcanic materials. The photograph of the outcrop is shown on figure 4c. The rock has a layered sedimentary structure with an orientation of N118°E/28°. This unit lies over the marble-lensed phyllite unit and is intruded by the microdiorite unit, suggested forming metasiltstone.

4.4. Microdiorite unit
This unit covers about 30% of the study sites. The description of the rock based on field observation of station 17 of figure 2, is an intrusive igneous rock with a phaneritic texture of 1–2 mm crystal size, holocrystalline, subhedral crystal form, massive structure, major mineral compositions are plagioclase and pyroxene with few accessory minerals of hornblende. The photograph of the rock can be seen on figure 4d. This unit intrudes all rock units in the study area, which evidenced by the presence of contact metamorphism on the siltstone forming metasiltstone, and the occurrence of skarn.
Figure 4. Field photograph of outcrops showing a variety of lithology found on the research area. Stations mentioned in this caption refers to figure 2. A) Phyllite with marble lenses denoted by red lines, approximately parallel to foliation plane on station 15. B) Carbonate breccia with phyllite fragments on station 14. C) Siltstone on station 18. D) Microdiorite on station 17. E) Metasiltstone showing striations that indicates a minor sinistral strike-slip fault on station 10. F) Skarn surrounded by metasiltstone on station 11. G) Photograph of hand sample of skarn taken from station 11. Grt: garnet; Cpx: clinopyroxene. H) Photograph of hand sample taken from station 15 showing marble lenses between phyllite.
4.5. Metasiltstone unit
This unit covers about 10% of the study sites. The description of the rocks based on field observation of station 10 of figure 2, is a light-gray brownish color with hornfelsic structure. This unit has resulted from the process of contact metamorphism between microdiorite and siltstone to form a baked margin. The field photograph is shown on figure 4e.

4.6 Skarn unit
This unit is only found in an outcrop of 8 m long and 6 m wide (Station 11 of figure 2), surrounded by metasiltstone. It is difficult to determine whether the outcrop is ex-situ or in-situ. Apart from being found in a fairly large outcrop, this unit is also found as a float along the Kluwihan creek with the trend of NW-SE (Figures 2 and 3). The lithological description of skarn rocks is a dark green rock with dark red spots, crystal size <1–3 mm, subhedral-euhedral crystal shape, consisting of dark red garnet minerals and greenish minerals clinoopyroxene and epidote groups. The field photograph and the hand sample of the skarn rock is shown on figures 4f and 4g, respectively. It has foliated structure that formed by aggregates of red garnet, green clinoopyroxene, and whitish clinohumite. This structure is suggested from relict foliation of the Ca-rich regional metamorphic protolith (calc-silicate phyllite or marble).

Table 1. Summary of thin section analysis of the study area.

| No | Lithology          | Sample code | Mineral Composition |
|----|--------------------|-------------|---------------------|
|    |                    |             | Qr | Ms | Chl | Cpx | Opx | Czo | Grt | Cal | Opq | Gr  | Hem | Act | PI | Zeo | Ser | Ep |
| 1  | Microdiorite       | WNM 01      | -  | -  | □   | O   | △   | -   | -   | △   | -   | △   | O   | -   | -   | -   | -   | -   |
| 2  | Metasiltstone      | WNM 07A     | □  | -  | O   | △   | -   | △   | -   | △   | -   | △   | -   |     | -   |     | -   | -   |
| 3  | Microdiorite       | WNM 07B     | -  | -  | □   | O   | △   | -   | △   | -   | △   | -   | △   | -   | -   | -   | -   | -   |
| 4  | Skarn              | WNM 09      | -  | -  | -   | -   | -   | -   | -   | △   | -   | △   | -   | -   | -   | -   | -   | -   |
| 5  | Phyllite           | WNM 10A     | O  | □  | O   | -   | -   | -   | △   | △   | △   | -   | △   | -   | -   | -   | -   | -   |
| 6  | Marble lense       | WNM 10B     | O  | □  | □   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   |
| 7  | Skarn              | WNM 11      | -  | □  | □   | □   | O   | △   | △   | -   | △   | -   | △   | -   | -   | -   | -   | -   |
| 8  | Metasiltstone      | WNM 20      | □  | -  | -   | △   | -   | △   | △   | -   | △   | -   | △   | -   | -   | -   | -   | -   |
| 9  | Metasiltstone      | WNM 22      | O  | -  | □   | -   | -   | △   | △   | -   | △   | -   | △   | -   | -   | -   | -   | -   |
| 10 | Skarn              | WNM 23      | △  | △  | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   |
| 11 | Metasiltstone      | WNM 27      | O  | -  | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   |
| 12 | Phyllite           | WNM 28      | O  | □  | □   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   |
| 13 | Phyllite breccia   | WNM 29      | □  | □  | □   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   |
| 14 | Phyllite           | WNM 30      | O  | □  | □   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   |
| 15 | Siltstone          | WNM 33      | O  | □  | □   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   |
| 16 | Siltstone          | WNM 36      | O  | -  | □   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   |
| 17 | Phyllite           | WNM 41      | O  | △  | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   |
| 18 | Phyllite           | WNM 44      | O  | △  | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   |
| 19 | Metasiltstone      | WNM 45      | O  | -  | □   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   | △   |

Qz = Quartz; Ms = muscovite; Chl = chlorite; Cpx = clinoopyroxene; Opx = orthopyroxene; Czo = clinohumite; Grt = garnet; Cal = calcite; Opq = opaque; Gr = graphite; Hem = hematite; Act = actinolite; Pl = plagioclase; Zeo = zeolite; Ser = sericite; Ep = epidote

5. Thin section petrographic analysis
The results of the petrographic analysis carried out on the samples taken from the study area are shown in table 1. Microdiorite from station 1 (Figure 5a) shows plagioclase, clinoopyroxene, and chlorite-epidote minerals. Figure 5b from station 14 shows the thin section of carbonate breccia with phyllite fragments with matrix composed of carbonate mud. Figure 5c from station 10 shows a thin section of metasiltstone showing a very fine saccharoidal texture, consisted of quartz, plagioclase, and pyroxenes. Spotted texture of hematite is also observed. Figure 5d from station 18 is the thin section of siltstone,
shows medium-sorted dominated by quartz, plagioclase, and pyroxene minerals, some of which have been oxidized to hematite. Figure 5e from station 15 shows a thin section of graphite-mica-chlorite phyllite characterized by a lepidoblastic texture appearance, intercalated by granoblastic minerals of quartz and albite. Figure 5f showing a contact between marble lenses and chlorite-quartz-muscovite phyllite, also found on station 15. The thin section of a skarn, that is actinolite-clinozoisite skarn from floats found on station 19, which shown in figure 5g, showing decussate texture composed of clinozoisite, actinolite, quartz, and garnet. Figure 5h from station 11 shows a thin section of skarn with decussate texture composed of clinozoisite, actinolite, quartz, and garnet. The actinolite content is more abundant.

**Figure 5.** Thin section images of representative samples of the studied location. A) Microdiorite; B) Carbonate breccia; C) Metasiltstone; D) Siltstone; E) Graphite-chlorite-mica phyllite; F) Marble contact with phyllite; G) Clinozoisite-actinolite skarn; H) Clinozoisite-actinolite skarn. Explanation of these thin sections is on section 5 of this paper.
6. Discussion
The geological history of the research area is marked by the formation of regional metamorphic rocks in the form of mica phyllite with marble lenses. Mineralogical compositions and rock textures (Table 1) imply that the metamorphic rocks originated from pelitic intercalated with carbonate protoliths, thus forming marble lenses in the phyllite (Figure 4a). The boudinage shown by marble, as well as the phyllitic foliation structure, might indicate that the rocks experienced ductile deformation during the metamorphism.

The occurrence of basal carbonate breccias with phyllite fragments (Figures 4b and 5b) implies that the metamorphic rock was exposed followed by erosion, and lithified into breccia. Those are indicated by an unconformity between the metamorphic and the breccia rocks. Carbonate matrix and cement that form the breccia suggest that the rock was formed in the marine environment. The sedimentary rock of siltstone might indicate that the rock was deposited in the environment with low current velocity. After the siltstone has been deposited and lithified, the magmatic activity of intrusion occurred which interact with country rocks (metamorphic and sedimentary rocks), of which responsible for the contact metamorphism. The metasiltstone has suggested the product of the contact metamorphism between microdiorite and siltstone. The rock exhibit more compact with hornfelsic texture compared to the original rock of siltstone (Figures 4c and 4e). Common contact metamorphic minerals (andalusite, cordierite, etc.) are not identified in this rock, probably because the microdiorite formed as shallow intrusion with faster cooling processes. It is confirmed by the medium-grained of crystal size (1–2 mm) in the microdiorite (Figure 4a).

Skarn in the research area was found as floats with the maximum size of 8 m length along the Kluwihan creek (Figures 3b and 4f). Skarn is a calc-silicate rock made by metasomatic processes of igneous intrusion body with carbonate rocks [5]. There are 2 types of carbonate rocks as a candidate of the skarn protolith found in the research area, which are marble lenses in the phyllite and the carbonate breccia. However, carbonate breccia was only found as a single float in the research area (Station 14, figures 4b and 5b). Hence, highly possible of the protolith skarn rocks is marble lenses in the phyllite, which quite common to find within the metamorphic rocks elsewhere in Jiwo Hills [1; 4]. The major composition of highly calc-silicate rich minerals of pyroxene and epidote (Table 1) might be indicating as a calcic skarn type [6; 7; 8]. Furthermore, greenish color (Figure 4g) with high ratio of pyroxene and epidote to garnet might indicate that the skarn rocks in the Cemorosewu Area are on the zone of exoskarn with prograde assemblages [6; 7; 8]. The retrograde assemblages (clinozoisite, actinolite; Figure 5h) [6; 7; 8] were found in the skarn that located in the northeastern of study area (Stations 19 and 4; Figure 2). This might be implied that the heat source of the skarn formation more likely located in the southwestern of the research area, which is proved by the occurrence of microdiorite intrusion. However, this needs to be further confirmed by geochemical analyses. Other than skarn formation, indications of silicic alteration are also observed, mainly in the phyllite which shows brecciated phyllite with secondary quartz matrix, overprinted by quartz vein.

7. Conclusion
The lithology in the Cemorosewu area consists of metamorphic, sedimentary, and igneous rocks. The regional metamorphic rocks consist of mica phyllite, graphite phyllite, quartzite and marble lenses. Regional metamorphic rocks are the oldest units exposed in the study area. The contact metamorphic rocks exposed in the study area are metasiltstone and skarn. Sedimentary rocks found in the study area include siltstone and carbonate breccias with phyllite fragments. The sedimentary rock units unconformably overlay the regional metamorphic rock units. Igneous rock that appears in the study area is microdiorite, which intrudes the rocks above, manifested by metasiltstone and skarn. The major composition of skarn minerals are garnet, pyroxene, and epidote indicate that the skarn is a calcic skarn and part of the exoskarn zone. The prograde assemblage of skarn is located in the southwestern of the research area nearby the microdiorite intrusion. While retrograde assemblage of skarn is located in the northeastern of the research area. Further detailed investigation, including geochemical analyses, is needed to constrain this conclusion.
Acknowledgments
We would like to thank the Geological Engineering Department of UGM and RTA Program for providing the research grant to facilitate this research.

References
[1] Setiawan N I, Osanai Y and Prasetyadi C 2013 Proc. Seminar Nasional Kebumian Ke-6 (Yogyakarta) 12–24.
[2] Surono, Hartono U, and Permanadewi S 2006 Geo-Res. 15 302–11.
[3] Dharmawan A G and Setijadji L D 2014 Studi Ubahan Batuan Tipe Skarn di Desa Pagerjurang, Kecamatan Bayat, Kabupaten Klaten, Propinsi Jawa Tengah [unpublished thesis] (Yogyakarta: Universitas Gadjah Mada) 164.
[4] Barianto D H, Margono U, Husein S, and Novian M I 2017 Geological map of Wonosari Quadrangles, Jawa (1408-31), Scale 1:50000 (Bandung: Geological Survey Centre)
[5] Harlov D E and Austrheim H 2013 Metasomatism and the Chemical Transformation of Rock (Berlin: Springer) p 806
[6] Meinert L D 1992 Geosci. Canada 19 145–162.
[7] Fila-Wojcicka E 2000 Acta Geol. Polonica 50 211–222.
[8] Kuscu I 2001 Turkish Jour. of Earth Sci. 10 121–132.