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RESEARCH ARTICLE

Effect of Porphyritic Andesite Intrusion on The Formation of Contact Metamorphism Aureole in Selo Gajah Hill Clastic Limestone, Bojonegoro Regency, East Java, Indonesia

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Abstract

At Selo Gajah Hill, Jari Village, Gondang Sub-district, Bojonegoro Regency, East Java there are limestone intruded by porphyritic andesite. The intrusion produces contact metamorphisms in the wall rocks. It is very interesting to study the protolith rock, facies of metamorphism and the zonation of contact metamorphism aureole. This research uses field observation method and laboratory analysis i.e. petrographic analysis. Field observation is conducted by doing geological mapping in the Bukit Selo Gajah area and rock sampling for petrographic analysis. Petrographic analysis aims to describe the texture of the rocks and the percentage of minerals, which will be used to determine the protolith rock, metamorphism facies and the determination of contact metamorphism zone. The lithology found in Mount Selo Gajah from oldest to youngest are clastic limestone with intercalation of marl, marl with intercalation of sandstone, porphyritic andesite intrusions, hornfels, and pyroclastic breccia. Metamorphic rocks on Selo Gajah Hill is the product of contact metamorphism of carbonate rock which was intruded by porphyritic andesite intrusion. The metamorphism facies found in the research area are hornblende hornfels and pyroxene hornfels with the protolith rock is carbonate rocks. Metamorphism zone in Selo Gajah Hill is divided into two zones: The zone closest to the intrusion body is vesuvianite zone or idiocrase zone with a radius of 40-140 m from the outer part of the intrusion body and the monticellite zone with radius ranging from 25 to 75 m from the outside of the vesuvianite zone.

Keywords: Bukit Selo Gajah, hornfels, contact metamorphism zone, andesite intrusion

1. Introduction

The research is held in Bukit Selo Gajah, Jari Village, Gondang District, Bojonegoro Regency, East Java Province. In regional geology, the research area is included in the Regional Geological Maps of Bojonegoro Sheet 1508-5 (Pringgoprawiro and Sukido, 1992). Based on the regional geological map, the lithology found in Bukit Selo Gajah are limestone intruded by porphyritic andesite. The intrusion produces contact metamorphism in the limestone.

From the standpoint of petrology, the essence of metamorphism is the chemical reaction among minerals and fluid (Ferry et al., 2011). Previous work on contact metamorphism of sedimentary rocks has demonstrated that 1) pure carbonates recrystallize without significant devolatilization, 2) limestones and marlstones are characterized by calc- silicate formation during heating, releasing CO_2- dominated and H_2O- bearing fluids (Aarnes et al., 2011a) (Aarnes et al., 2011b).

Experimental studies show that carbonates partially melt at relatively low temperature, but natural examples of such melting are rare (Ganino et al., 2013). Contact metamorphism of igneous rocks will cause metamorphic zones distinguished by mineral assemblage, depend on initial rock composition (Deer et al., 2013). The purpose of this research is to study the distribution of lithology, stratigraphy and facies of metamorphism in Bukit Selo Gajah and surrounding areas.

2. Regional Geology

Based on the division of physiographic zone according to (Van Bemmelen, 1949), the study area is a part of the Quaternary Volcanic Zone and Kendeng Antiklinorium. This zone is adjacent to the Central Depression Zone in the south and Randublatung Zone in the North in Fig.1.The stratigraphic condition of the research area consists of three formations, they are Kalibeng Formation, Andesite Intrusion, and Pandan Breccia which can be seen in Fig. 2.

The Kalibeng Formation consists of a rich fossil-greenish grey marl interbedded with tuff. This sediment is deposited in the bathyal environment. The upper part of the Kalibeng Formation (Atasangin Member) consists of fine-coarse tuffaceous sandstone, tuff, and volcanic breccia. This sediment is deposited by the turbidite mechanism (Pringgoprawiro and Sukido, 1992). This formation is of late Miocene – Pliocene (Fig. 2). Pyroxene andesite is an intrusion of porphyritic andesite with a high content of pyroxene. This formation is of Pleistocene age. Pandan breccia is a Pleistocene pyroclastic breccia. Study area is part of Pandan Volcanic Complex, consist of Nangka Volcano, Lawang Volcano, and Pandan Volcano. This complex is characterized by andesitic rocks as pyroclastics and intrusions (Arhananta et al., 2018). Selo Gajah hill located in the north of the main Pandan Volcano.

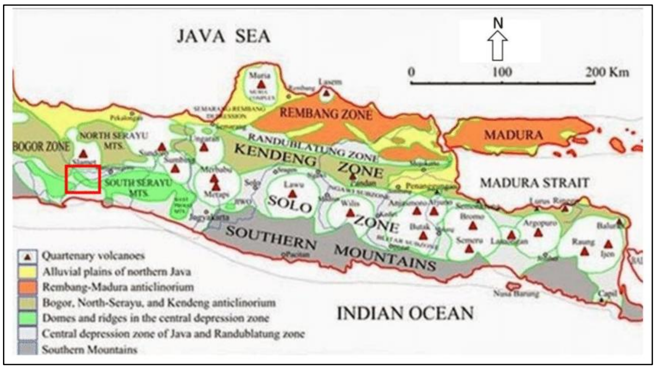

Fig. 1. Physiography of Eastern part of Java (Van Bemmelen, 1949)

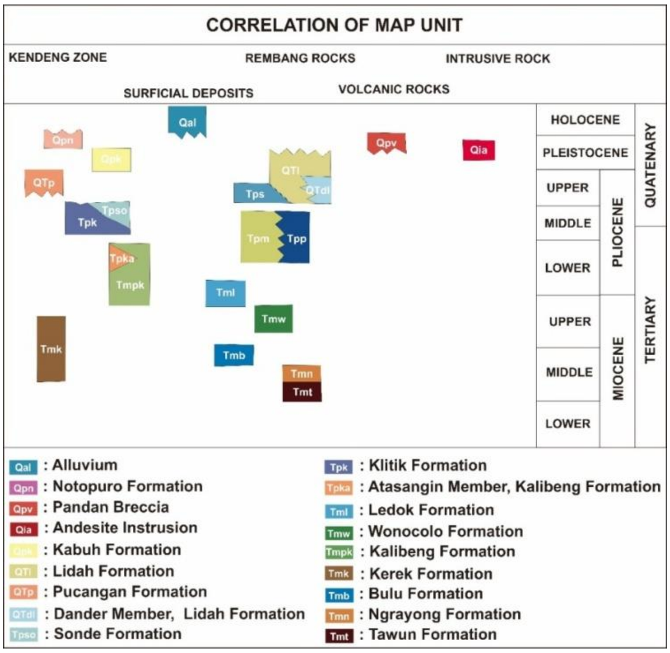

Fig. 2. The stratigraphy of Kendeng Zone (Pringgoprawiro and Sukido, 1992)

3. Research Methods

This research is conducted by doing literature study, field observation, laboratory analysis and data analysis. The laboratory analysis used in this research is petrographic analysis to find out the structure, texture, and mineral composition in rocks. The data of petrographic analysis is used to determine the protolih rock, the facies of metamorphism and the contact metamorphism aureole zonation.

4. Results and Discussion

4.1 Stratigraphy

From the geological mapping in the research area, there are five units of lithology found in the research area. Those lithology from oldest to youngest are clastic limestone, marl (carbonate claystone), porphyritic andesite, hornfels (metamorphic rock), and pyroclastic breccia (Fig. 3-4). The explanation of each lithology unit is as follows.

Clastic Limestone

The oldest lithology unit in the research area consists of clastic limestone with intercalation of marls (Fig. 5). The rock color is generally blackish gray. In megascopic appearance, there are found some cavities which are the result of dissolution. Based on petrographic analysis,the rock composition consists of 10% shell of the organism, 30% algae which part of the body has been replaced by calcite mineral, 30% brown rock matrix/ micrite and light brown sparite, and 30% porosity which is the result of dissolution. Based on the composition, this rock is Floatstone (Embry and Klovan, 1971).

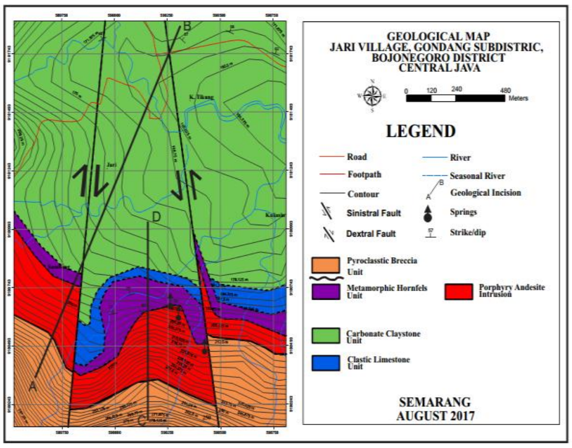

Fig. 3. Geological map of Selo gajah Hill, Jari Village, Gondang Sub-District, Bojonegoro

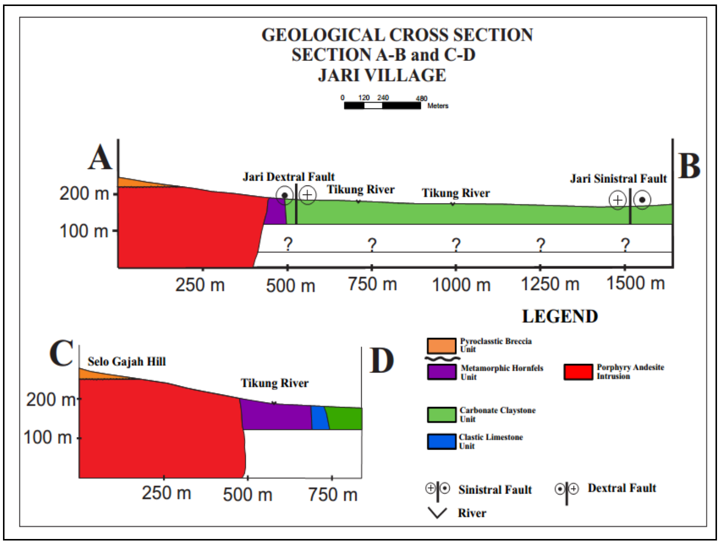

Fig. 4. Geological cross section of Jari Village, Gondang Sub-District, Bojonegoro District

Fig. 5. (A) The outcrop of clatic limestone at STA 32. (B) Handspeciment of clastic limestone, (C) Petrographic appearance of clastic limestone

Marl (Carbonate Claystone)

This lithology unit consists of marls with the intercalation of carbonate sandstones (Fig. 6). In general, the rocks have the strike direction of east-west with the strike/dip direction N 280°E/58°.

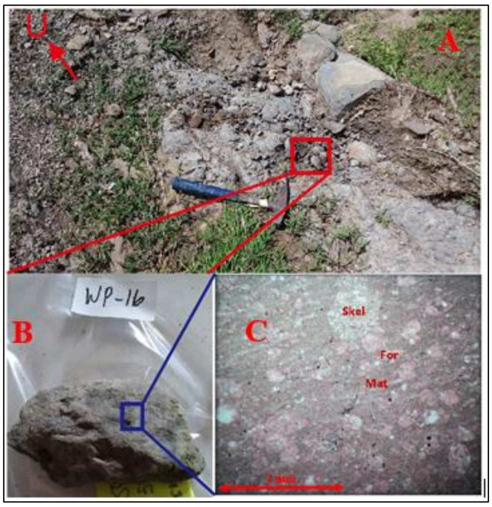

Fig. 6. (A) The outcrop of marls at STA 28 (B) Handspeciment of marls (C) Petrographic appearance of marls

Porphyritic andesite

The unit of porphyritic andesite intrusion is a lithology that is unconformably intruded the lithological units of clastic limestone with intercalation of marls and marls with intercalation of carbonate sandstone. Because of the intrusion the areas near the intrusive body underwent contact metamorphism (Fig. 7).

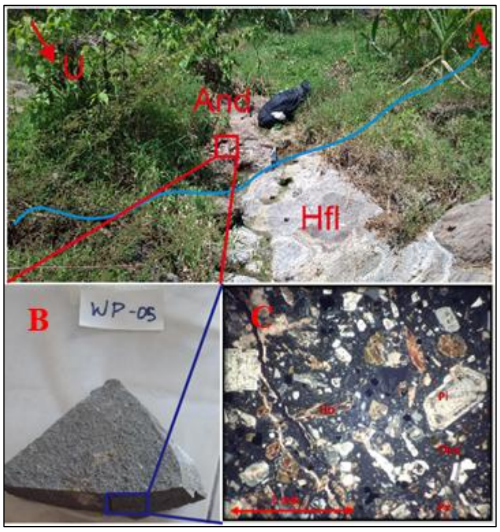

Fig. 7. (A) The contact of porphyritic andesite intrusion (And) and hornfels (Hfl) at STA 9 (B) Handspeciment of porphyritic andesite (C) Petrographic appearance of porphyritic andesite

The rock color is generally gray. In megascopic appearance, the rock structure is massive with the rock texture is porphyritic. In microscopic appearance, the rock composition consists of 50% plagioclase (andesine) as phenocryst and groundmass,10% pyroxene as a groundmass, 15% hornblend as phenocryst and groundmass,5% sanidine as base mass, and quartz at 5% as groundmass. Based on the composition, the rock has the name Porphyritic Andesite (Thorpe and Brown, 1985).

Hornfels

The lithology unit of hornfels metamorphic rock consists of sedimentary rock which is transformed to metamorphic rock due to the influence of andesite porphyritic intrusion (Fig. 8). In general, the rocks have the strike direction of east-west with the strike/dip direction 270°E/77°.

In general, the color of the rocks is bright white and blackish gray. In megascopic appearance, there are found some cavities which are the result of dissolution. In microscopic appearance, the thin section of rock shows hornfelsic/ granulose structure and granoblastic textures while the special textures are crystalloblastic and decussate. The composition of the rocks consist of wollastonite minerals (15%), vesuvianite (30%), spurrite (25%), calcite (15%), and monticellite (15%). Based on the composition, the rock is Metacarbonate-rock (Robertson, 1999) and Marble (Huang, 1962).

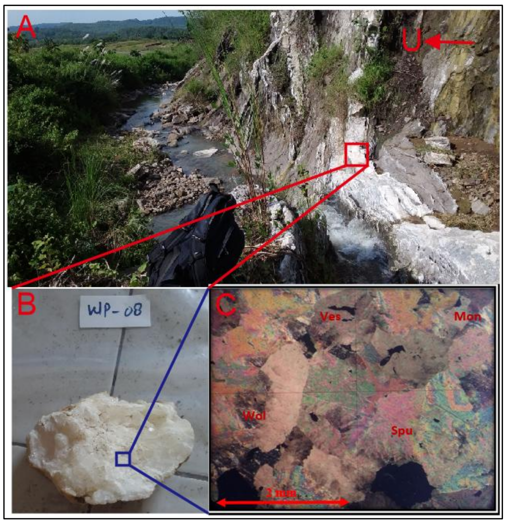

Fig. 8. (A) The outcrop of hornfels at STA 30 (B) Handspeciment of hornfels (C) Petrographic appearance of hornfels

Pyroclastic Breccia

The lithology unit of pyroclastic breccia is unconformably deposited above the andesite porphyritic intrusion. This can be seen through the appearance of rock contacts in the field at STA 15 and STA 24. Pyroclastic breccia covers porous andesite intrusions. The appearance of pyroclastic breccia can be seen in Fig. 9. In general, this rock found in the field is weathered.In megascopic appearance, the color of rocks is generally grayish brown with a massive structure. The fragments of the breccia are composed of andesite with the matrix is tuff-lapilli.

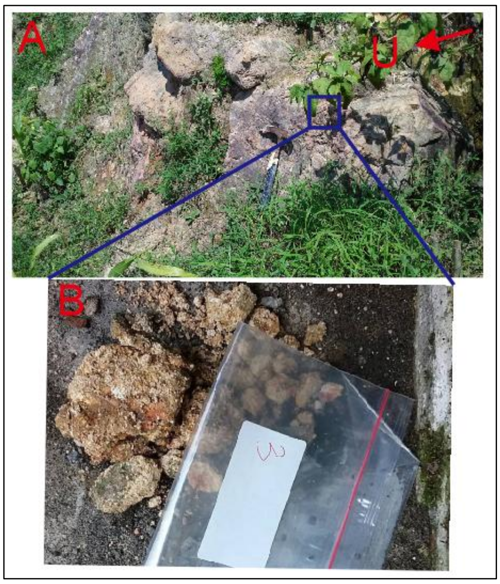

Fig. 9. (A) The outcrop of pyroclastic breccias at STA 30 (B) Handspeciment of pyroclastic breccia

4.2 Mineralogy

Rock sampling is conducted systematically, based on three types of rocks: sedimentary rock as protolith rock of hornfels, igneous rocks as intrusion rocks, metamorphic rocks as a product of contact metamorphism.

The rock sampling location can be seen at Figure 10. There are 19 rock samples were taken, consist of 8 sedimentary rocks (Table 1), 5 igneous rocks (Table 2), 6 metamorphic rock (Table 3). Those samples then will be analysed with petrographis analysis. Petrographic analysis includes observations of rock and mineral textures, and mineral composition of rock constituents. Following are the observations of rock mineralogy in each sample.

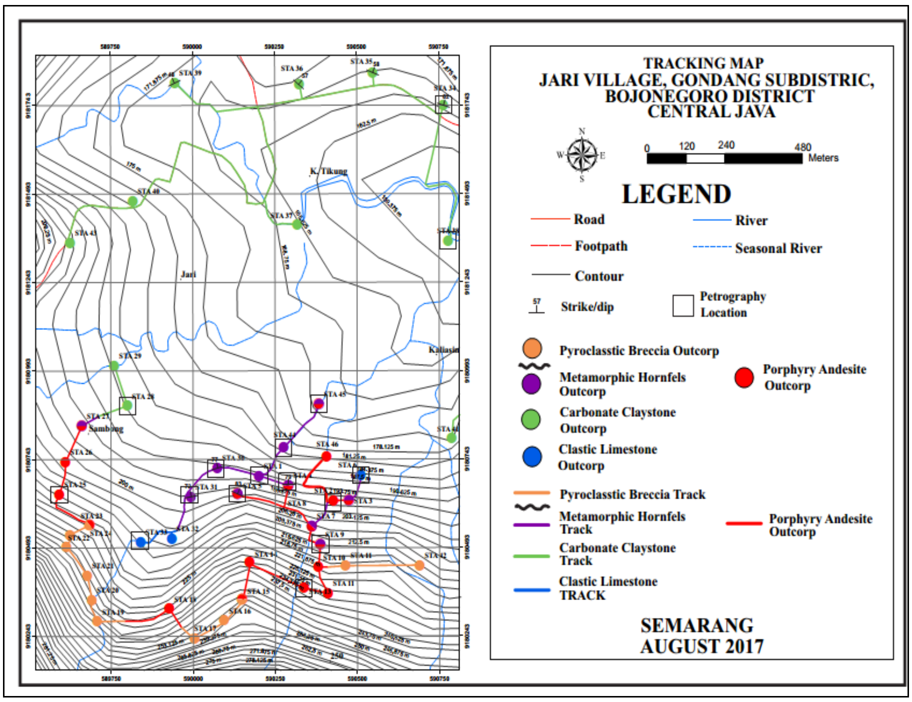

Fig. 10. Tracking map of Selo Gajah Hill, Jari Village, Gondang Sub district, Bojonegoro District

Table 1 shows the minerals which compose the sedimentary rock in the research area. Sedimentary rock in the research area near the intrusion body is considered to be a protolith in the research area. These mineral were used to indicate the type of sedimentary rock in the research area to support the research. The determination of rocks is based on the classification of (Embry and Klovan, 1971). The Embry and Klovan classification (1971) considers the composition of the constituents in rocks and the size of fragments in carbonate rocks. Based on the composition, the carbonate rocks in the research area consists of Wackestone, Packstone and Floatstone.

Table 2 shows the minerals which compose the igneous rock in the research area. These minerals were used to indicate igneous rock types in the research area to support the research. The determination of rocks is based on the classification of (Thorpe and Brown, 1985) by considering the composition of the constituent minerals in the rocks. Based on the composition of minerals in igneous rocks, the rock is classified as porphyritic andesite.

Table 3 shows the minerals which compose the metamorphic rock of the research area. These minerals were used to determine metamorphic rock types in the research area to support the research. The determination of rocks based on the classification of (Robertson, 1999) and (Huang, 1962) by considering the composition of the constituent minerals in rocks. Based on the composition of minerals in metamorphic rocks , the rock is classified as Metacarbonate-rock (Robertson, 1999) and Marble (Huang, 1962).

Table 1. The mineralogy of sedimentary rock at research area

Sample	STA	Composition (%)						Rock name
		Alg	For	Skel	Mat	Cal	Por	
WP-04	STA 44	-	-	15	35	50	-	Packstone
WP-07	STA 33	30	-	10	30	-	-	Floatstone
WP-13	STA 13	10	-	30	20	15	20	Floatstone
WP-15	STA 09	35	-	10	55	-	-	Floatstone
WP-16	STA 21	-	35	10	55	-	-	Wackestone
WP-17	STA 31	-	40	10	30	20	-	Floatstone
WP-18	STA 34	-	30	10	60	-	-	Wackestone
WP-19	STA 37	-	20	10	70	-	-	Wackestone

Note: Alg : Algae, For : Foraminefera, Skel : Skeletal grain, Mat : Matrix, Cal : Calcite, Por: Porosity

Table 2. The mineralogy of igneous rock at research area, all rocks are porphyritic andesite

Sample	STA	Composition (%)						
		Pl	San	Px	Lit	Qz	Hb	Opq
WP-02	STA 13	50	5	10	10	5	15	5
WP-05	STA 09	50	5	10	10	5	15	5
WP-06	STA 02	55	5	10	-	5	20	5
WP-10	STA 25	50	5	10	-	5	25	5
WP-11	STA 05	50	5	10	10	5	15	5

Note: Pl : Plagioclase, Lit : Lithic, Qz : Quartz, Hb: Hornblende, Opq : Opaque Mineral, San : Sanidine, Px : Pyroxene

Table 3. The mineralogy of metamorphic rock at research area

Sample	STA	Mineral Composition (%)								
		Wol	Ves	Spu	Fos	Cal	Mon	Tre	Opq	Til
WP 011	1	30	20	25	10	15	10			
WP 012	1	25	40	25		5	5			
WP 013	1	15	25	15	5	10	15	10		
WP 03	4		20	25		30	5		25	
WP 08	30	15	30	25		15	15			
WP 09	6		10	15		65	10			
WP 12	45		35	35		15	15			
WP 14	31		15	15		55	5			10

Note: Wol : Wollastonite, Ves : Vesuvianite, Spu : Spurrite, Fos : Foshagite, Cal : Calcite, Mon : Monticellite, Tre : Tremolite, Opq : Opaque Mineral, Til : Tilleyite

4.3. The Metamorphic Facies and The Protolith Rock at Selo Gajah Hill

The determination of metamorphic facies is determined by looking at the mineral composition in metamorphic rocks. Calcite is one of mineral that can form metamorphic minerals. Calcite has a chemical formula of $CaCO_3$. Wollastonite is formed by the loss of carbon dioxide which is then replaced by silica. The chemical reaction of wollastonite formation is:

$$CaCO_3 + SiO_2 \rightarrow CaSiO_3 + CO_2$$

Wollastonite is formed at a temperature of 600°-700° C with a pressure of 0.2 GPa according to (Deer et al., 2013)Tremollite is formed at a temperature of 600°-700° C with a pressure of 0.5 GPa (Bucher and Grapes, 2011). The chemical reaction of tremollite formation is:

$$5CaMg(CO_3)_2 + 8SiO_2 + H2O \rightarrow Ca_2Mg_5Si_8O_{22}(OH)_2 + 3CaCO_3 + 7CO_2.$$

Spurrite has chemical formula of $Ca_5(SiO_4)_2(CO_3)$. According to Deer et al. (1998) spurrite formed due to the intrusion of andesitic to basaltic rocks to the carbonate rocks s with temperatures of 600°-800° C.

According to (Winkler, 1979) spurrite can be formed due to the release of CO2 by tilleyite at the highest temperature of 900° C. Foshagite has the chemical formula of $Ca_4Si_3O_9$ $(OH)_2$. The temperature and pressure of foshagite formation are the same with wollastonite, but in the foshagite formation, there is hydrogen enrichment by water. Monticellite has the chemical formula $CaMgSiO_9$. Monticellite formed due to the intrusion of granitic to basaltic to the carbonate rocks.Vesuvianite has the chemical formula of $Ca_{19}(Al,Fe)_{10}(Mg,Fe)_3[Si_2O_7]_4[SiO_4]_{10}(O,OH,F)_{10}$.

Vesuvianite formed in areas closest to intrusion bodies with the protolith rock rich in carbonate minerals. The type of intrusion also determines the facies and minerals resulted from the metamorphism. In the research area, the type of intrusion is included in the porphyritic andesite.

According to (Winkler, 1979) the presence of minerals of monticellite, melilite, larnite, merwinite, wollastonite and spurrite are minerals resulted from contact metamorphisms with high temperatures and formed in shallow intrusions with rapid cooling. The presence of spurrite, wollastonite and monticellite according to (Winkler, 1979) suggests that it is classified as sanidinite facies. Based on the mineral composition showing the temperature and pressure formation and the presence of minerals that show the facies of sanidinite, the facies of metamorphism can be determined as hornblende hornfels - sanidinite hornfels which can be seen in Fig. 11.

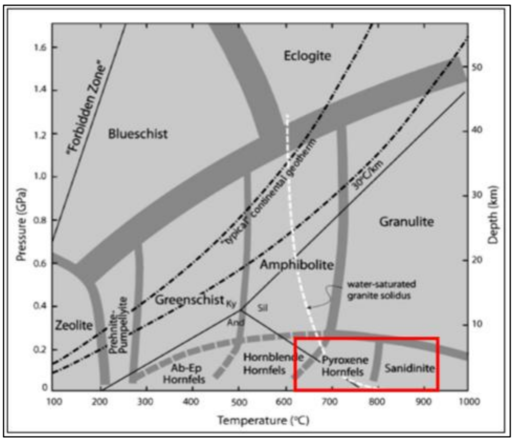

Fig. 11. The facies of metamorphism at Selo Gajah Hill, Jari Village, Gondang Sub distric, Bojonegoro

4.4.The Zonation of Contact Metamorphism at Selo Gajah

The determination of contact metamorphism zonation on limestones uses a model made by (Burnham, 1959). This model will be modified according to the conditions in the research area. The determination of this zone is based on mineral composition in the research area. The minerals used in the determination are minerals on metamorphic rocks. The location of metamorphic rock sampling for petrographic analysis can be seen in Fig. 12.

The metamorphic zonation map is arranged based on mineral composition in rock samples (Table 3), lithology unit boundaries and structural geology. Based on mineralogy, metamorphic zone can be divided to three zone. From the inner to outer are: unaffected zone, monticellite zone, and vesuvianite zone. The map of influence of contact metamorphism can be seen in Fig. 12.

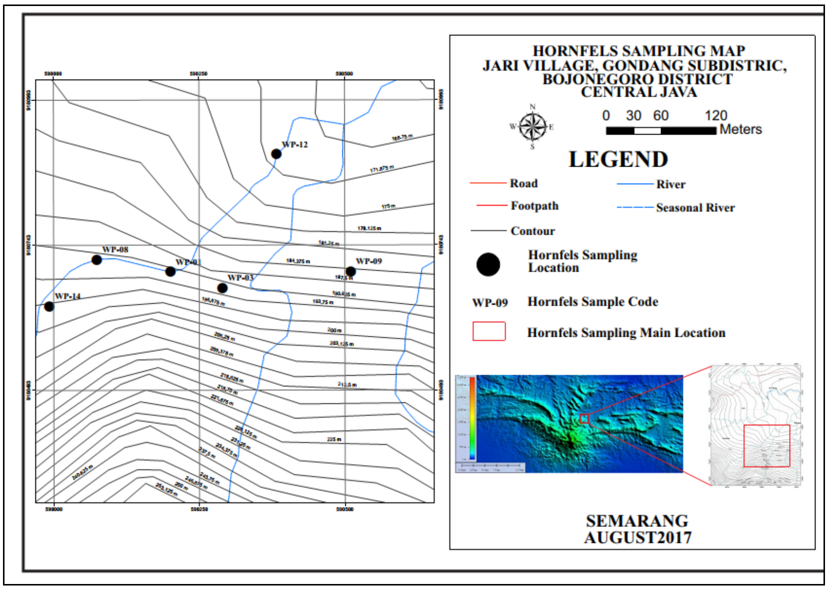

Figure 12. Hornfels sampling map at Selo Gajah Hill, Jari Village, Gondang Sub District, Bojonegoro

This zonation map (Fig. 13) can provide information the radius effect of metamorphism experienced by carbonate sedimentary rocks. The zone closest to the intrusion body is the vesuvianite or idocrase zone. The radius of vesuvianite zone ranges from 40 to 140 meters from the outside of the body of the intrusion. The zone outside of the vesuvianite zone is the monticellite zone. The montizellite zone radius ranges from 25 to 75 meters from the outside of the vesuvianite zone (Fig.14).

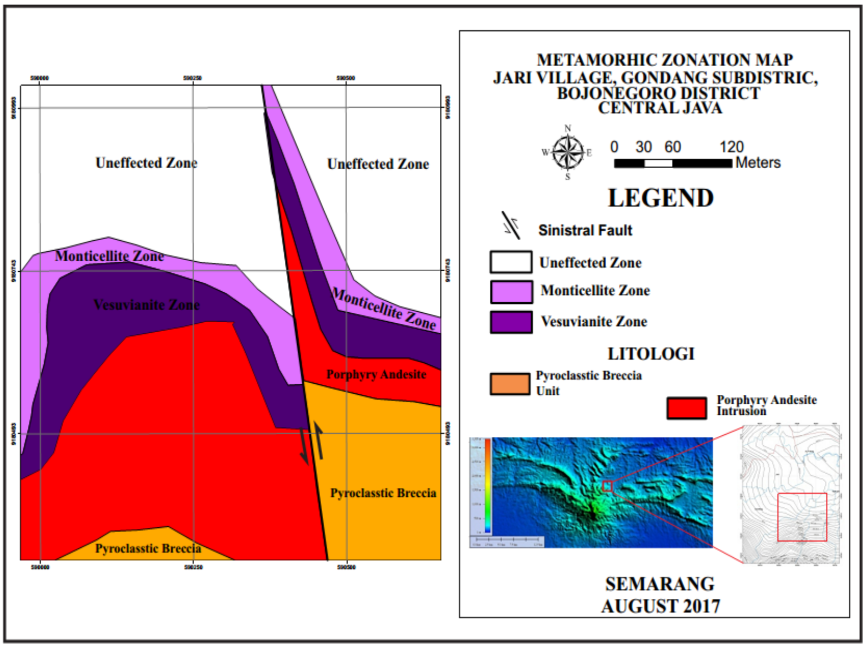

Figure 13. Metamorphic zonation map at Selo Gajah Hill, Jari Village, Gondang Sub District, Bojonegoro

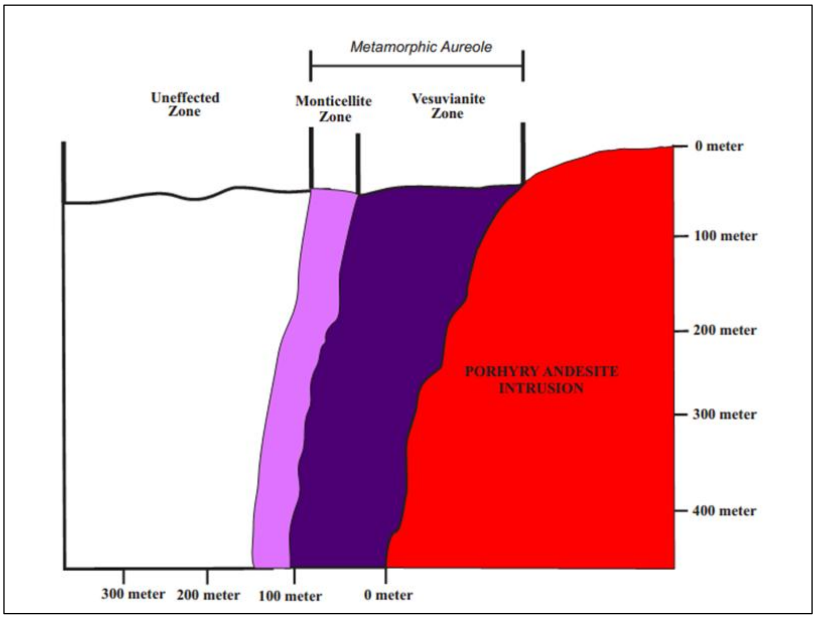

Figure 14. The vertical cross section of contact metamorphism effect zonation at Selo Gajah Hill, Jari Village, Gondang Sub distric, Bojonegoro

The zones outside of the vesuvianite zone and monticellite zone is a zone that does not experience the effect of metamorphism so the rock is not changed. The forsterite zone and garnet zone were not found in the research area due to the absence of identifier minerals such as grossular, klinohumite, forsterite, and clintonite.

5. Conclusion

Metamorphic rocks in the Selo Gajah Hill are the result of contact metamorphism from carbonate sedimentary rocks that are intruded by porphyritic andesite intrusion.The facies of metamorphism in Selo Gajah Hill are hornblend hornfels - sanidinite hornfels with the protolith rocks came of carbonate sedimentary rocks.

The zonation of metamorphism in Selo Gajah Hill is divided into two zones, they are the zone closest to the intrusion body is the vesuvianite or idocratic zone with a radius of 40-140 meters from the outside of the intrusion body and the monticellite zone with a radius ranging from 25 - 75 meters from the outside of the vesuvianite zone.

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References

Aarnes, I., Fristad, K., Planke, S., Svensen, H., 2011a. The impact of host-rock composition on devolatilization of sedimentary rocks during contact metamorphism around mafic sheet intrusions. Geochemistry, Geophys. Geosystems 12, n/a-n/a. https://doi.org/10.1029/2011GC003636

Aarnes, I., Svensen, H., Polteau, S., Planke, S., 2011b. Contact metamorphic devolatilization of shales in the Karoo Basin, South Africa, and the effects of multiple sill intrusions. Chem. Geol. 281, 181–194. https://doi.org/10.1016/j.chemgeo.2010.12.007

Arhananta, Arina, I., Purwanto, J., Mendel, J., Setiawan, J., 2018. Kinematik Struktur Geologi Daerah Atasangin, Kecamatan Sekar, Bojonegoro, Jawa Timur dan Implikasinya terhadap Aktivitas Magmatisme Gunung Pandan, in: Seminar Nasional Kebumian Ke-11. Universitas Gadjah Mada, Yogyakarta.

Bucher, K., Grapes, R., 2011. Petrogenesis of Metamorphic Rocks. Springer Berlin Heidelberg, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-74169-5

Burnham, C.W., 1959. Contact Metamorphism of Magnesian Limestones at Crestmore, California. Geol. Soc. Am. Bull. 70, 879.

Deer, W.A., Howie, R.A., Zussman, J., 2013. An Introduction to the Rock-Forming Minerals. Mineralogical Society of Great Britain and Ireland. https://doi.org/10.1180/DHZ

Embry, A.F., Klovan, J.E., 1971. A Late Devonian Reef Traction on Northeastern Banks Island, N.W.T.1. Bull. Can. Pet. Geol. 19, 730–781. https://doi.org/https://doi.org/10.35767/gscpgbull.19.4.730

Ferry, J.M., Ushikubo, T., Valley, J.W., 2011. Formation of Forsterite by Silicification of Dolomite during Contact Metamorphism. J. Petrol. 52, 1619–1640. https://doi.org/10.1093/petrology/egr021

Ganino, C., Arndt, N.T., Chauvel, C., Jean, A., Athurion, C., 2013. Melting of carbonate wall rocks and formation of the heterogeneous aureole of the Panzhihua intrusion, China. Geosci. Front. 4, 535–546. https://doi.org/10.1016/j.gsf.2013.01.012

Huang, W.T., 1962. Petrology. McGraw-Hill Education, New York.

Pringgoprawiro, H., Sukido, 1992. Peta Geologi Regional Skala 1:100.000 Lembar Bojonegoro. Bandung.

Robertson, S., 1999. BGS Rock Classification Scheme Volume 2: Classification of metamorphic rocks. Nottingham.

Thorpe, R., Brown, G., 1985. The Field Description of Igneous Rocks. Open University Press, University of California, California.

Van Bemmelen, R.W., 1949. The Geology of Indonesia. Vol.IA: General Geology of Indonesia and Adjacent Archipelagoes. Government Printing House, The Hague, Netherlands.

Winkler, H.G.F., 1979. Petrogenesis of Metamorphic Rocks. Springer New York, New York, NY. https://doi.org/10.1007/978-1-4757-4215-2