Metamorphic Evolution of Garnet-bearing Epidote-Barroisite Schist from the Meratus Complex in South Kalimantan, Indonesia

NUGROHO IMAM SETIAWAN¹, YASUHITO OSANAI², NOBUHIKO NAKANO², TATSURO ADACHI², and AMRIL ASY’ARI³

¹Geological Engineering Department, Faculty of Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia
²Division of Earth Sciences, Faculty of Social and Cultural Studies, Kyushu University, Fukuoka, Japan
³Mining Department, Banjarmasin State Polytechnic, Banjarmasin, Indonesia

Corresponding author: nugroho.setiawan@ugm.ac.id
Manuscript received: January 6, 2015; revised: March 4, 2015; approved: August 26, 2015; available online: October 23, 2015

Abstract - This paper presents metamorphic evolution of metamorphic rocks from the Meratus Complex in South Kalimantan, Indonesia. Eight varieties of metamorphic rocks samples from this location, which are garnet-bearing epidote-barroisite schist, epidote-barroisite schist, glaucophane-quartz schist, garnet-muscovite schist, actinolite-talc schist, epidote schist, muscovite schist, and serpentinite, were investigated in detail its petrological and mineralogical characteristics by using polarization microscope and electron probe micro analyzer (EPMA). Furthermore, the pressure-temperature path of garnet-bearing epidote-barroisite schist was estimated by using mineral parageneses, reaction textures, and mineral chemistries to assess the metamorphic history. The primary stage of this rock might be represented by the assemblage of glaucophane + epidote + titanite ± paragonite. The assemblage yields 1.7 - 1.0 GPa in assumed temperature of 300 - 550 °C, which is interpreted as maximum pressure limit of prograde stage. The peak P-T condition estimated on the basis of the equilibrium of garnet rim, barroisite, phengite, epidote, and quartz, yields 547 - 690 °C and 1.1 - 1.5 GPa on the albite epidote amphibolite-facies that correspond to the depth of 38 - 50 km. The retrograde stage was presented by changing mineral compositions of amphiboles from the Si-rich barroisite to the actinolite, which lies near 0.5 GPa at 350 °C. It could be concluded that metamorphic rocks from the Meratus Complex experienced low-temperature and high-pressure conditions (blueschist-facies) prior to the peak metamorphism of the epidote amphibolite-facies. The subduction environments in Meratus Complex during Cretaceous should be responsible for this metamorphic condition.

Keywords: garnet-bearing epidote-barroisite schist, pressure-temperature path, high-pressure metamorphic rocks, Meratus Complex, South Kalimantan

How to cite this article:
Setiawan, N. I., Osanai, Y., Nakano, N., Adachi, T., and Asy’ari, A., 2015. Metamorphic Evolution of Garnet-bearing Epidote-Barroisite Schist from the Meratus Complex in South Kalimantan, Indonesia. Indonesian Journal on Geoscience, 2 (3), p.139-156. DOI:10.17014/ijog.2.3.139-156

INTRODUCTION

Background
The Meratus Complex lies in the South Kalimantan extending in trend of NE-SW (Figure 1). The metamorphic rocks cropping out in this location have been considered as part of Cretaceous subduction fossils in central Indonesia, which widely spread throughout Central Java, South Sulawesi, and South Kalimantan (Miyazaki et al., 1996; 1998; Parkinson et al., 1998; Kadarusman et al., 2007). The studies of the high-pressure metamorphic rocks, especially their prograde and retrograde pressure-temperature paths, provide important constraint on the tectonic processes of ancient subduction zone in the central Indonesia.
Zulkarnain (2003) reported the occurrences of quartz-chloritoid rocks from this location and concluded it was derived from pelitic schist in an accretionary complex environment. Moreover, Sikumbang and Heryanto (2009) reported occurrences of several metamorphic rocks from this location. One of them is barroisite-epidote schist. Parkinson et al. (1998) described the occurrence of glaucophane- and kyanite-bearing quartz schist in this location and also suggested that the presence of Mg-rich chloritoid implied recrystallization at pressure of ~1.8 GPa or higher, which recommended as a part of high-pressure metamorphic terranes in central Indonesia (Luk-Ulo Complex in Central Java, Bantimala Complex in South Sulawesi). However, detailed observations of P-T evolution, particularly on the reaction texture of prograde, peak, and retrograde
stages have not been reported. In this paper, we present a petrographic description and minerals chemistry analysis of representative samples of newly found garnet-bearing epidote-barroisite schist from the Meratus Complex, South Kalimantan (Figures 1 and 2), and discuss its P-T evolution. Mineral chemistries of representative samples were analyzed using JEOL JXA-8530F electron probe micro analyzer (EPMA) at Kyushu University, Japan. The analytical condition of EPMA was set an accelerating voltage of 15 kV, a probe current of 12 nA and a beam diameter of 2 μm. Natural mineral samples (ASTIMEX-MINM-53) and synthesized oxide samples (P and H Block No. SP00076) were used as standards for the quantitative chemical analyses. Mineral abbreviation in this paper follows Whitney and Evans (2010).

Constraining the prograde peak and retrograde P-T path are very important for geodynamic interpretations in the region. Particularly in high-pressure metamorphic terranes, prograde to retrograde histories are relevant to the processes of deep subduction and subsequent exhumation. The

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**Figure 2.** Simplified geological map and sample localities in the Meratus Complex, South Kalimantan (modified after Sikumbang and Heryanto, 2009). Insert map is location of the complex within the Kalimantan Island.
conclusion will address the metamorphic evolution of Meratus Complex and possible linkage with the other metamorphic terranes in central Indonesia. Furthermore, the authors also compare the results of the study with other high-pressure metamorphic terranes in central Indonesia (Bantimala Complex, South Sulawesi; Luk Ulo Complex, Central Java) for the sake of reconsidering the Mesozoic tectono-metamorphic development of the eastern margin of the Sundaland.

**Geological Outline**

The Cretaceous subduction complex, which is represented by the occurrence of accretionary unit including mélanges, pillow basalts, dismembered ophiolites, cherts, serpentinites, and garnet lherzolite are sporadically exposed in the central Indonesia region through the Java, Kalimantan, and Sulawesi Islands (Sukamto, 1982; Wakita et al., 1994a, 1994b, 1996, 1998; Miyazaki et al., 1996, 1998; Parkinson et al., 1998; Wilson and Moss, 1999; Kadarusman and Parkinson, 2000). The distribution of the accretionary units and metamorphic rocks are shown in Figure 1. Most of the metamorphic rocks exposing in the complexes occur in a limited areas and are bounded by the thrust fault with other units such as dismembered ophiolites, cherts, mélanges, and serpentinites (Sukamto, 1982; Asikin et al., 2007; Sikumbang and Heryanto, 2009).

In the Meratus and Bobaris Mountains of South Kalimantan, the metamorphic rocks crop out in the most southern part of the Meratus Mountains namely as the Meratus Complex. The Meratus Complex extends in the trend of NE–SW (Sikumbang and Heryanto, 2009; Figure 2). The metamorphic rocks occur as wedge-shaped tectonic blocks in fault contact with ultramafic rocks and Cretaceous sedimentary rocks (Parkinson et al., 1998). The dominant lithologies in this complex are serpentinized peridotite and pyroxenite, gabbrro, plagiogranite intrusions, shale-matrix mélanges with clasts of limestone, chert and basalt (Laut Island), pelagic sediments with a Middle Jurassic-late Early Cretaceous radiolarian biostratigraphy, clastic and carbonate sediments, and various low-grade schists (Wakita et al., 1998; Parkinson et al., 1998; Sikumbang and Heryanto, 2009). These formations are unconformably overlain by Late Cretaceous turbidites and volcanioclastics (Figure 2). Cretaceous magmatic rocks of island-arc with calc-alkaline affinity intruded the Meratus Complex (Yuwono et al., 1988). The magmatic rocks are rhyolite, dacite, andesite, basalt, granite, diorite, and gabbro with the age ranges of 92 - 72 Ma (Yuwono et al., 1988).

Sikumbang and Heryanto (2009) reported metamorphic rocks of quartz-muscovite schist, quartzite, barroisite-epidote schist, and metabasalt. Parkinson et al. (1998) described the occurrence of glaucophane- and kyanite-bearing quartz schist in this location. They also suggested that the presence of Mg-rich chloritoid implied recrystallization at a pressure of ~1.8 GPa or higher. The K-Ar dating of various mica schists yielded ages ranging between 110 - 180 Ma, which are in the similar age with the metamorphic rocks in South Sulawesi and Central Java (Wakita et al., 1998; Sikumbang and Heryanto, 2009). Furthermore, Wakita et al. (1998) and Parkinson et al. (1998) suggested the occurrence of high-pressure metamorphic rocks in this location were products of a Cretaceous subduction beneath Sundaland.

**Results and Analyses**

**Modes of Occurrences and Sample Descriptions**

The blueschist- to amphibolite-facies rocks (e.g. epidote-barroisite schist discussed in this study) occur in the Aranio River (Figures 2 and 3a - c). The schist consists of garnet- and quartz-rich layers which has 80ºW trending foliation from north with dipping 66º to north (Figures 3b and c). In the southern part of the complex, only serpentinized peridotites were identified as metamorphic rocks and the others are ultramafic rocks and mafic rocks such as peridotite, olivine-gabbro, and hornblende-gabbrro. The exposure of serpentinite could be found throughout in the complex (Figures 2 and 3d). Other types of metamorphic rocks are mainly tremolite-talc schist, muscovite schist, and epidote schist. However,
the geological relationships between the schists and the serpentinites have not yet been clarified because of poor exposures due to deep weathering and heavily vegetated areas.

The mineral assemblages of collected samples are listed in Table 1. General petrographical characteristics of representative metamorphic rocks collected from the Meratus Complex are also described below. Fe$^{3+}$ contents of garnet were calculated using algorithm suggested by Droop (1987). Phengite formulae have been calculated on the basis of eleven oxygen atoms with assuming all iron to be Fe$^{2+}$. Nomenclatures and calculated composition of the amphiboles follow Leake et al. (1997).

**Epidote-barroisite schists**

Epidote-barroisite schists show nematoblastic texture derived from the abundant barroisite and epidote (Figure 4a). The other assemblages are quartz, titanite, hematite, and apatite. Greenish blue barroisite nematoblast (X$_{Mg} = 0.58 - 0.67$, (Na + K)[$\mathbf{A}$] = 0.15 - 0.31) is ~0.2 mm in length. Glaucophane (X$_{Mg} = 0.61$, (Na + K)[$\mathbf{A}$] = 0.11) grains are included into the barroisite, indicating precursor blueschist-facies metamorphism. Quartz and titanite are also included into the barroisite. Chlorite replaces barroisite and other minerals along the cracks which indicates secondary phases.

**Garnet-bearing epidote-barroisite schists**

These rocks have fine-grained garnet (0.1 - 0.5 mm in diameter) along with epidote, barroisite, titanite, quartz, albite, and phengite, with or without apatite (Figure 4b). Granoblastic garnet (Prp11-18Alm53-60Sps8-10Grs14-24) has inclusions of quartz and epidote. Nematoblastic
Barroisite (0.1 - 0.3 mm in length; XMg = 0.62-0.67, (Na + K)\[A\] = 0.23 - 0.35), epidote, and lepidoblastic phengite (~0.2 mm in length; XSi = 0.61 - 0.64) form schistosity in the rock. Some of them are replaced by chlorite and albite during retrograde metamorphism.

Epidote-glaucophane schists

These rocks mainly consist of glaucophane, quartz, epidote, phengite, and titanite with or without hematite and apatite (Figure 4c). Excluding quartz, glaucophane, phengite, and epidote are ubiquitous in matrix. Glaucophane (~0.25 mm in diameter; XMg = 0.64 - 0.67, [Na + K]\[A\] = 0.02 - 0.77) and epidote (~0.2 mm in diameter) show sheaf texture and sometimes show random orientation. Several fine-grained phengites (<0.05 mm in diameter; XSi = 0.64 - 0.67) also show random orientation. Secondary chlorite, calcite, and albite replace glaucophane, phengite, and epidote along the cracks.

Garnet-muscovite schists

These rocks have porphyroblastic texture with numerous garnet porphyroblasts (Figure 4d). These samples mainly consist of garnet, muscovite, quartz, epidote, rutile, albite, and apatite. A lot of cracks appear in the coarse-grained garnet (0.5 - 1 mm in diameter). Those cracks are filled with chlorite and albite. Muscovite (~0.25 mm in diameter) and epidote (~0.3 mm in diameter) are abundant in the matrix. Those minerals develop the schistose fabric of these rocks. Secondary chlorite subsequently replaces garnet and other minerals by pseudomorph after them.

Tremolite-talc schist

This rock is rarely found in study area. It consists of tremolite, talc, and quartz (Figure 4e). Sheaf texture of tremolite (~0.5 mm in diameter) is embedded in the abundant talc grains. Interstitial albite and quartz occur filling in the cracks.

Serpentinite

Serpentinite preserves relict mineral phases. Clinopyroxene and olivine are well recognized under polarized microscope despite suffering from crosscut by mesh texture of serpentine (Figure 4f). Spinell (0.2 - 0.5 mm in diameter) occurs in the matrix which consider as a relict mineral.

Petrology and Mineral Chemistry of Garnet-bearing epidote-barroisite Schist

The estimation of P-T paths of the high-pressure metamorphic rock (garnet-bearing epidote-barroisite schist; Sample no. 031601) from the Meratus Complex is described in detail in this section. The estimated metamorphic evolution in this chapter could reflect the evolution of the Meratus Complex of South Kalimantan. General petrography of the rock sample discussed here has already been described in the previous section. Hence, in this section, the description of petrography and mineral chemistry will focus on the selected garnet-bearing epidote-barroisite schist sample with mineral coexistence on that is mainly described in detail.
Detailed petrography

The garnet-bearing epidote-barroisite schist can be subdivided into garnet-bearing and -free domains. On the garnet-bearing domain, fine-grained garnet, epidote, barroisite, titanite, quartz, and phengite coexist (Figure 5a). In the garnet-free domain, barroisite, epidote, titanite, quartz, albite, and phengite coexist. The schistosity of this rock is mainly defined by barroisite, phengite (~0.2 mm), and epidote (~0.15 mm). Core portion of

Figure 4. Photomicrographs of metamorphic rocks from Meratus Complex. (a), Foliation of epidote-barroisite (Ep-Brs) schist; (b), foliation of garnet-bearing epidote-barroisite (Grt-bgEp-Brs) schist; (c), bluish elongated glaucophane (Gln) occur with epidote (Ep), phengite (Ph), and quartz (Qz); (d) garnet- muscovite (Grt-Ms) schist with secondary chlorite (Chl) pseudomorph after garnet (Grt); (e), nematoblastic actinolite within matrix talc in tremolite-talc (Tr-Tlc) schist; (f) mesh texture in serpentinite (Srp) with relict olivine (Ol) and clinopyroxene (Cpx). The scale bar without expression in each of photomicrograph on this publication indicates 1 mm.
fine-grained garnet (0.1 - 0.5 mm) has inclusions of quartz, titanite, apatite, chlorite, and epidote (Figure 5b). Blue-greenish barroisites (0.5 - 1 mm) show compositional heterogeneity suggested by patchy texture of Si-rich and Si-poor barroisites (Figure 5c). In several grains, thin layer of actinolite rims the barroisites (Figure 5d). Some of the barroisites are replaced by chlorite and albite, which indicate secondary phases in this rock.

**Mineral chemistry**

Mineral chemistries of the garnet-bearing epidote-barroisite schist are described in detail. The analyses were performed using the same system as described in the previous section. Representative mineral chemistry analyses of the garnet-bearing epidote-barroisite schist are presented in Table 2.

**Garnet**

Euhedral garnet obviously has two domains defined by a different composition, which show core and rim portions (Figure 6). The garnet has a barrier reef type zoning pattern identified by an irregular/anhedral shape of core portion (Figure 6). Enami et al. (2011) studied the barrier reef garnet grains from Myanmar eclogite and they suggested that relics of an older core occurring as fragments were dissolved by the new garnet. The chemical zoning on the garnet is clearly identified on the Ca, Fe, Mg, and slightly on the Mn elements (Figure 6). Epidote, titanite, and apatite are inclusions in the core portion of garnet which are clearly identified particularly by Ca and Ti elements (Figure 6). Based on the chemical zoning (rim to core),
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Table 2. Representative Microprobe Analyses of Garnet, Phengite, Amphibole, Epidote, and Titanite

| Mineral Position | Garnet | Phengite | Amphibole | Epidote | Ttn |
|------------------|--------|---------|----------|---------|-----|
|                  | core   | rim ↑   | I        | II↑     | inc | matrix | matrix | inc | matrix | inc |
| SiO₂             | 37.75  | 38.29   | 46.11    | 51.38   | 53.57 | 49.05  | 42.15  | 52.05 | 37.51  | 38.10 | 30.76 |
| TiO₂             | 0.18   | 0.05    | 0.62     | 0.09    | 0.22  | 0.16   | 0.68   | 0.07  | 0.17   | 0.08  | 36.24 |
| Al₂O₃            | 21.38  | 21.34   | 29.97    | 24.29   | 5.84  | 7.05   | 13.15  | 3.20  | 25.35  | 25.89 | 2.25  |
| Cr₂O₃            | 0.00   | 0.00    | 0.06     | 0.03    | 0.10  | 0.03   | 0.05   | 0.03  | 0.00   | 0.00  | 0.02  |
| FeO              | 24.39  | 27.84   | 3.18     | 3.09    | 17.62 | 19.23  | 19.93  | 16.37 | -      | -    | -    |
| Fe₂O₃            | -      | -       | -        | -       | 10.42 | 9.69   | 2.07   |       |        |      |
| MnO              | 4.58   | 3.27    | 0.05     | 0.09    | 0.27  | 0.42   | 0.28   | 0.33  | 0.45   | 0.22  | 0.42  |
| MgO              | 2.61   | 4.62    | 1.68     | 3.16    | 9.75  | 9.88   | 7.43   | 13.43 | 0.11   | 0.01  | 0.09  |
| CaO              | 9.51   | 5.20    | 0.00     | 0.00    | 3.92  | 8.16   | 9.83   | 10.07 | 22.70  | 23.63 | 26.98 |
| Na₂O             | 0.04   | 0.02    | 1.12     | 0.14    | 5.35  | 3.18   | 3.00   | 1.71  | 0.00   | 0.02  | 0.04  |
| K₂O              | 0.00   | 0.03    | 9.64     | 10.93   | 0.08  | 0.25   | 0.95   | 0.11  | 0.00   | 0.02  | 0.01  |
| Total            | 100.43 | 100.65  | 92.43    | 93.59   | 96.72 | 97.39  | 97.44  | 97.36 | 96.69  | 97.66 | 98.87 |

Table 2. Representative Microprobe Analyses of Garnet, Phengite, Amphibole, Epidote, and Titanite

The garnet core portion has increased in grossular and decreased in almandine and pyrope (Prp10-15Alm53-58Sps8-11Grs18-24; Figure 7). The rim portion of the garnet shows increasing pyrope and almandine but decreasing in grossular with spessartine that are relatively flat (Prp16-18Alm59-61Sps7-10Grs13-16; Figure 7). The increasing spessartine components along the garnet cracks (Sps18-20) might be an effect of retrograde metamorphism.

**Phengite**

Two types of phengite were recognized in the matrix (phengites 1 and 2). The differences between both phengites are obviously identified by the chemical mapping images of Na, Fe, Mg, Al, and Si elements (Figure 8). The phengite 1 is richer in Na and Al but lesser in Si, Mg, and K elements (XNa = 0.141-0.151; XSi = 0.566-0.571; XMg = 0.480-0.528; Figure 9a), whereas phengite 2 has higher XSi values in the core (XNa = 0.019-
Amphibole

Amphiboles occur as lepidoblast in the matrix. The internal textures of amphiboles are obviously identified in the back-scattered images (Figures 9c, d). Barroisites patch with higher-Si contents (Si = 7.05 - 7.23; XMg = 0.58 - 0.60; Na[B] = 0.70 - 0.87; hereafter called barroisite I) included in coarse-grained Si-poor barroisite grain (barroisite II) with composition ranging Si = 6.39 - 6.88, XMg = 0.46 - 0.57, and Na[B] = 0.41 - 0.75 (Figures 5c-d, 10. Rarely Na-rich am-

Figure 6. Back-scattered and chemical mapping images on the garnet in garnet-bearing epidote-barroisite schist from Meratus Complex on the response of Ca, Na, Fe, Mn, Mg, Al, Si, and Ti elements. The chemical zoning on the garnet is clearly identified on the Ca, Fe, Mg, and slightly on the Mn elements. The garnet has a barrier reef type zoning pattern which is identified by an irregular/anohedral shape of core-portion clearly identified in Ca component. Mn components increase along the garnet cracks that might indicate a secondary stage. Grt = garnet; Ap = apatite; Ep = epidote; Chl = chlorite; Ab = albite; Ph = phengite.
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Phengites are also included in the barroisite, which are plotted in the winchite and glaucophane fields (Si = 7.72 - 7.81; XMg = 0.61 - 0.63; Na[B] = 1.40 - 1.60; Figures 5c-d, 10). Thin layer of actinolite rims the barroisites in the matrix which have richer-Si and lower-Na[B] components. Those are with composition ranging Si = 7.42 - 7.69, XMg = 0.62 - 0.70, and Na[B] = 0.44 - 0.82 (Figures 5c-d, 10).

**Other minerals**

Other minerals are epidote, titanite, chlorite, and albite. Those are describing in here. There are no significant differences between epidotes that occur as the inclusion and in the matrix. Both of them have similar ranges of pistacite contents (XFe$^{3+}$ = 0.18 - 0.30). Titanite as inclusion in garnet core have higher-XAl (0.084 - 0.275) than titanite in the matrix (XAl = 0.084 - 0.275). Chlorite occurring along cracks of garnet and replacing other minerals has a compositional range of XFe = 0.44 - 0.46. Albite occur as interstitial phases along the cracks of barroisite and in the matrix has composition of XAb = 0.98 - 1.00.

**Discussion of P-T Estimation**

Based on the textural and mineral chemical results, the metamorphic evolution of the garnet-bearing epidote-barroisite schist is divided into three stages which represents the different metamorphic facies as follows: prograde (blueschist-facies), peak (amphibolite-facies), and retrograde stages (greenschist-facies). Summary of mineral assemblages and their chemical characters are presented in Table 3.

**Prograde Stage**

The prograde stage of garnet-bearing epidote-barroisite schist might be preserved as mineral inclusions, composed of glaucophane that is included in the barroisite in the matrix and the epidote in the garnet core. As described previously, two kinds of phengite were identified in the matrix (Figure 8) which are Na-rich phengite (phengite 1) and normal phengite (phengite 2). The Na-rich phengite (phengite 1) might be pseudomorph after paragonite. Hence, the primary stage of this rock might be represented by the assemblage of glaucophane + epidote ± paragonite (Table 3).
The equilibrium reaction of Lws + Jd = Pg + Ep/Zo + Qz + H2O + Vapor from Heinrich and Althaus (1988) might give a minimum temperature for primary stage as lawsonite and Na-clinopyroxene that could not be found in this rock (Figure 11). The presence of glaucophane grains included in the barroisite can be used to constrain the maximum temperature of prograde stage. The maximum temperature of glaucophane is based on experimental studies of natural glaucophane by Maresch (1977) at temperature 550 ºC above 1.0 GPa (Figure 11). Therefore, petrogenetic grid from Evans (1990) suggests the primary stage occupies the epidote blueschist-facies stability field (Figure 11; Table 3).

Titanite and epidote grains are included in the garnet core (Figure 5b). Rutile, which is not observed in the garnet inclusion, appears in the matrix. Manning and Bohlen (1991) suggested geobarometry involving titanite, rutile, epidote...
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Figure 9. Chemical characteristics of phengite grains. Phengites 1 and 2 are plotted on the [a] XSi vs. XMg and [b] XNa vs. XMg.

Figure 10. Compositional ranges of amphibole grains. Amphibole (Amp) grains included in the barroisite (Brs) are alkali amphibole straddling in the glaucophane (Gln) and winchite (Wnc) fields. Amphibole grains occurring in the matrix are barroisite and several grains straddle on the magnesio-hornblende (Mhb)/pargasite (Prg)/taramite (Trm) fields. Matrix rim rich in Si content but lower Na[B]. Those straddle in the barroisite/winchite/actinolite fields.
and grossular in eclogite was based on dehydration reaction of $\text{Ep} + \text{Ttn} = \text{Grs} + \text{Rt} + \text{Qz} + \text{H}_2\text{O}$. Garnet in this sample does not show an increase of grossular between core and rim. However, if other net-transfer reaction producing pyrope and almandine, sometimes the grossular weight % does not show increasing although it may be produced by that reaction. The equilibrium of titanite, epidote, and grossular in the garnet core was observed (Table 3). The activity of grossular component in garnet core was calculated from the mixing model of Berman (1990). The titanite,
clinozoisite/epidote, rutile, quartz, and H₂O activities were calculated following Manning and Bohlen (1991). Activity of titanite (Table 2) was calculated as \( X_{\text{Ca}}X_{\text{Ti}}\left[X_{\text{Si}}\right] \) with \( X_{\text{O}} = (5 - X_{\text{Al}} - X_{\text{Fe}^{3+}}) \) by assuming that F and OH substitutions were balanced by Al and Fe³⁺, which correspond to \( \alpha_{\text{Tis}} = 0.756 \). The activity of clinozoisite/epidote was calculated as \( X_{\text{Ca}}X_{\text{Al}}\left(1 - X_{\text{Fe}^{3+}}\right)X_{\text{Si}} \) with the maximum pistacite selected (Table 2) to give the maximum pressure corresponding to \( \alpha_{\text{Czo}} = 0.367 \). Other activities of rutile, quartz, and H₂O are assumed to be 1 (Manning and Bohlen, 1991). The activities of the assemblage yield 1.7 - 1.0 GPa for an assumed temperature of 300 - 550 °C interpreted as the maximum pressure limit of the prograde stage (Figure 11).

**Peak Stage**

Mineral coexistences at the peak P-T condition are garnet rim, barroisite, phengite 2, epidote, and quartz (Table 3). The temperature condition is estimated using the garnet-phengite geothermometer formulated by Krogh and Raheim (1978) and Green and Hellman (1982). The results give temperature ranges of 547 - 636 °C assuming 1.0 GPa (Figure 11). The peak pressures are estimated using phengite geobarometer formulated from Massone and Schreyer (1980). Maximum and minimum Si contents on phengite 2 are used for this geobarometer to obtain maximum and minimum pressures, respectively. The result gives a range of pressures at 1.1 - 1.5 GPa. Petrogenetic grid from Evans (1990) suggests that this peak P-T conditions are plotted on the epidote amphibolite-facies (Figure 11).

**Retrograde Stage**

The retrograde decompression stages in this rock are represented by textural relations of amphiboles in the matrix (Figures 5c - d). Following solid-solution diagram of amphiboles from Otsuki and Banno (1990), the retrograde P-T path is explained by changing chemical composition of amphiboles from Si-Na rich barroisite to actinolite rim through Si-Na poor amphiboles (barroisite II; Figures 5c-d, 11). Therefore, there are two stages in the retrograde metamorphism. The second or last retrograde-decompression P-T path should be on the stability field of actinolite (Table 3) which lies near 0.5 GPa at 350 °C (Figure 11).

**Conclusions**

It might be concluded that metamorphic rocks from the Meratus Complex experienced high-pressure condition of the epidote blueschist-facies before the peak metamorphism of the epidote-amphibolite facies. The worldwide blueschist-facies metamorphic rock is consided as markers of fossil subduction zones. As already mentioned before, the K-Ar dating of various mica schists in this location yielded ages ranging 110 - 180 Ma, which are in the similar age with the metamorphic rocks in South Sulawesi and Central Java. Therefore, the occurrences of prograde blueschist-facies in Meratus Complex might be concluded that this area was originally in subduction zone during Cretaceous age.
Compared to the other high-pressure metamorphic terranes in central Indonesia (e.g. eclogite from Bantimala Complex: 580 - 650 °C at 1.8 - 2.4 GPa and 630 - 700 °C at 2.9 - 3.1 GPa and eclogite from Luk Ulo Complex: 2.0-2.3 GPa at 365 - 410 °C and 2.15 - 2.25 GPa at 550 - 625 °C, the estimated P-T metamorphic condition of garnet-bearing epidote-barroisite schist from the Meratus Complex has a lower peak pressure but giving higher temperature (547 - 690 °C) at pressure 1.1 - 1.5 GPa. The high-pressure metamorphic rocks from Bantimala and Luk Ulo Complexes are characterized by low- to very low geothermal gradients. Furthermore, this study shows that garnet-bearing epidote-barroisite schist from the Meratus Complex has a higher geothermal gradient compared to the other metamorphic terranes. Possibly, the Meratus Complex was proximal and the others were distal with respect to the original Cretaceous subduction site. The results reported here and further precise petrological and geochronological studies will contribute toward a better understanding of the Mesozoic tectono-metamorphic development of the eastern margin of the Sundaland.

Acknowledgments

The authors would like to extend gratitudes to a staff member of the Mining Department, Banjarmasin State Polytechnic (POLIBAN), Mrs. Dessy Lestary for supporting geological field surveys in South Kalimantan, Indonesia. This work is part of the PhD study of first author financed by the JICA AUN/SEED-Net scholarship. Fieldworks are also supported by Grants-in-Aid for Scientific Research (No. 21253008 and 22244063 to Y. Osanai) from the Ministry of Education, Culture, Sports, Science, and Technology, Japan.

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