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RESEARCH ARTICLE

Petrology and Mineralogy of Metamorphic Rocks in The Pringsewu District, Lampung Province, Indonesia

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Abstract

The origin of metamorphic rock is greatly influenced by the temperature and pressure changes in every tectonic setting, especially in active subduction margins. One of the wide outcrops of metamorphic rock occurs in the Pringsewu District, Lampung, and it is a part of the Palaeozoic Gunung Kasih Complex. The presence of metamorphic rocks in Pringsewu has raised several questions and debates for some time due to the lack of research and field evidence found in this area, especially, since the origin of metamorphic rock in Lampung has been rarely studied. This research aims to determine the metamorphic rock facies and the tectonic setting underlying the formation of metamorphic rocks in the study area.

Petrographic analysis on 19 thin-section samples shows that metamorphic rock in the research area can be divided into two regions i.e., western and eastern regions. The Eastern part is characterized by muscovite-epidote schist and greenschist which consist of quartz, muscovite, actinolite, epidote, and garnet as index minerals. Whereas the western part is characterized by quartzite and biotite-epidote schist that consist of quartz, biotite, and muscovite. Based on the mineral index, metamorphic rock's protoliths are pelitic rock, mafic rock, and quartz-feldspathic sandstone. The metamorphic rock zonation shows the created temperature is from 280-550ºC.

The foliation structure such as schistose and porphyroblastic texture in the whole rocks sample indicated that metamorphic rocks are created in medium-grade metamorphism and are characterized by the greenschist facies to epidote-amphibolite facies. The abundance of quartz, k-feldspar, and labradorite minerals show that metamorphic rocks came from the microcontinent which was caused by a collision between the intra-oceanic Woyla plate and West Sumatra microcontinent in the Cretaceous. Indications of tectonic activity that create the lithology in Lampung Province need more geological study, especially to determine the absolute age of the metamorphic rock.

Keywords: Greenschist, Epidote-Amphibolite, Facies, Lampung, Pringsewu.

1. Introduction

Sumatra Island is in the SW part of Sundaland and it is restricted by Hindia-Australian subduction in the southern part (Barber et al., 2005; Hall, 2009; Metcalfe, 2017). The tectonic development of Sumatra Island is influenced by the Sumatran Fault System, which stretches Barisan Mountain from Aceh to Lampung (Barber & Crow, 2005b; Natawidjaja, 2018).

Lampung Province is in the southern part of Sumatra Island and is dominated by metamorphic rocks, volcanic rocks, and plutonic rocks which correlated with subduction events in Mesozoikum (Amin et al., 1994; Barber & Crow, 2005a; Mangga et al., 1994; Mccourt et al., 1996). Based on Amin et al., (1993) and Mangga et al. (1993), metamorphic rocks occurred as a basement rock, in Lampung, and were well exposed in Pringsewu District.

The widespread metamorphic rock outcrop in Pringsewu Regency is the main focus of this research. Pringseweu Regency is an area that has experienced rapid development, allowing metamorphic rocks to be well exposed along the main roads. However, human activity such as housing construction and agriculture has led to the easy disappearance of these metamorphic rocks. Although few studies have been conducted in this area, some previous research (Alditian, 2022; Dewinta, 2021; Prasetyo, 2023) indicated that Pringsewu Region has several types of metamorphic rocks that can be distinguished significantly based on petrological features, such as mica schist, etc.

The presence of metamorphic rocks in Pringsewu has raised several questions and debates for some time due to the lack of research and field evidence found in this area. One common debate revolves around the age of the metamorphic rocks in Lampung, in 1941, Westerveld (Barber & Crow, 2005a) drew a comparison between the age of the metamorphic rocks in Lampung and northern metamorphic rocks, such as Tapanuli Group in Aceh and Kuantan Formation in the Padang area, which is from the Paleozoic era. However, dating conducted by Mangga et al. (1994) suggests that Lampung's metamorphic rocks are 125±5 million years old, placing them in the Middle Cretaceous period (Mangga et al., 1994).

Furthermore, the origin of metamorphic rock in Lampung, based n petrological and petrography characteristics, has been rarely studied. However, it is noteworthy that some economic minerals, such as manganese and iron ore in Tanggamus and Pringsewu, are associated with the presence of metamorphic rocks in this region (Hendrawan & et al., 2022; Natalia et al., 2022; Subandrio, 2007). Moreover, there have been no studies indicating the differences in the characteristics of metamorphic rocks in Lampung compared to those in the Sunda Shelf, such as the Tarap Formation, Ciletuh Formation, Luk Ulo Formation, and Meratus Formation (Aterta & Hastuti, 2020; Ikhram et al., 2018; Miyazaki et al., 1998; Parkinson et al., 1998; Wakita et al., 1994, 1996, 1998) (**Table 1**).

In this study, petrological and mineralogical analyses of metamorphic rocks are conducted to determine the mineral assemblages constituting the metamorphic rocks, the protolith of the metamorphic rocks, and the temperature of metamorphic rock formation. This research aims to determine the metamorphic rock facies and the tectonic setting underlying the formation of metamorphic rocks in the study area.

2. Geology Regional

The metamorphic rocks in the study area are part of the Paleozoic-aged Gunung Kasih Tak Terpisahkan Complex (**Figure 1**). These metamorphic rocks consist of marble, schist, and quartzite (Amin et al., 1993; Mangga et al., 1993). According to Barber et al. (2005), these metamorphic rocks come from subduction between the intra-oceanic Woyla block and the South Sumatra block. Other researchers suggested that these metamorphic rocks originated from a Paleozoic volcanic arc or are part of allochthonous blocks that accreted to the edge of the Sunda Shelf in the late Paleozoic or early Mesozoic era (Barber et al., 2005; Hall, 2009; Metcalfe, 2017; Susilohadi, 2019). The presence of such metamorphic rocks also occurs in the southeastern part of the Sundaland (Soesilo et al., 2015).

The presence of metamorphic rocks such as phyllite, schist, slate, minor quartzite, and marble indicates that the metamorphic rocks are part of the greenschist facies, which formed similarly to the metamorphic rocks of the Tarantam and Kuantan Formations in Central Sumatra (Mangga et al., 1994). Comparisons between the metamorphic rocks in Lampung and the Kluet Formation led (Barber & Crow, 2005a) to suggest that the metamorphism in the Lampung area is of high grade. However, Amin et al. (1994) and Mangga et al. (1994) state that the metamorphic rocks in Lampung range from low-grade to moderate-grade metamorphism.

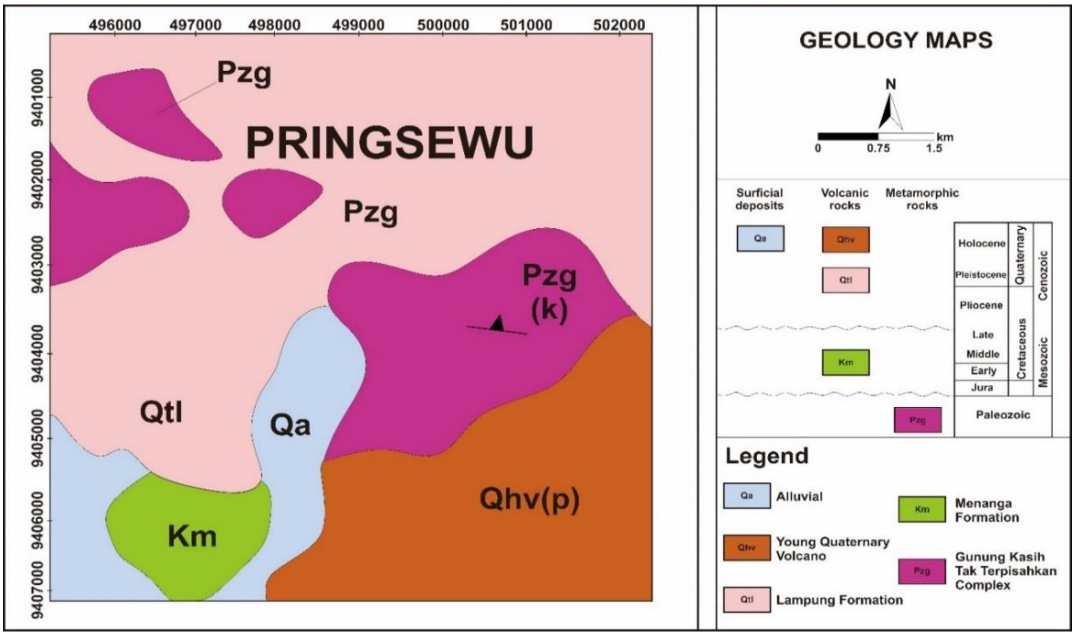


Fig 1. Geology map of the study area (Amin et al., 1993; Mangga et al., 1993)

The tectonic activity occurring in the western part of Sumatra is closely related to the formation of the Central and Southern Sumatra Basins (Barber et al., 2005; De Coster, 1974). These hydrocarbon-bearing basins have a metamorphic basement with similar characteristics to the Gunung Kasih Complex. Furthermore, the structural continuity in both basins extends to Bandar Lampung and is recorded in the foliation of the metamorphic rocks. The metamorphic rocks in the Gunung Kasih Complex exhibit an NW-SE foliation direction. These rocks have undergone two episodes of folding with east-west and NW-SE axial orientations, forming kink-bend structures in the outcrops of the study area (Barber & Crow, 2005b).

Although the presence of metamorphic rocks in the study area lacks evidence of uplift, Mangga et al. (1994) state that the Gunung Kasih Tak Terpisahkan Complex is a result of subduction activities during the Mesozoic era and is situated above the Cretaceous sedimentary rocks of the Menanga Formation. Furthermore, based on K-Ar dating, the age differences found suggest that the metamorphic rocks in Lampung are associated with syntectonic granite intrusions (Susilohadi, 2019).

3. Method

In this research, two methods were employed: geological mapping and petrography analysis. The geological mapping involved collecting 28 samples of metamorphic rocks from the western and eastern parts of the research area (Fig. 2). During field observations, detailed descriptions of rock foliation and mineralogy were recorded for rock identification and structural analysis in the study area.

Nineteen petrography data were analyzed at the Petrology Laboratory, Institut Teknologi Sumatra, using a polarizing microscope. The petrographic analysis involved examining the mineral abundance, rock structures, and textures, as well as microstructures of each sample to determine the protolith of the metamorphic rocks, the temperature of metamorphic rock formation, and the metamorphic rock's history of temperature changes.

The determination of the protolith types of the metamorphic rocks utilized classifications from Frost & Frost (2014) and Barrow (Winter, 2014). For the determination of metamorphic facies and formation temperatures, the facies table by Sen (2014) was employed. Additionally, microstructural analysis was conducted to determine the tectonic characteristics that formed the metamorphic rocks. This analysis utilized the microstructural classifications of Passchier & Trouw (2005) and Blenkinsop (2002). The determination of metamorphic zone formation temperatures is based on index minerals referred to by Reyes (1990) and Barrow (Winter, 2014).

Table 1. Comparison of metamorphic rocks in Sundaland and Sumatra based on some researchers.

Complexes and metamorphic grades	Rock Types			Age (Ma)
	Pelitic/Felsic rocks	Mafic/Intermediate rocks	Ultramafic/Calc-silicate rock	
Ciletuh Complex Greenschist, serpentinite [1]	Grt-Ms-Qtz schist Ms phyllite Ms-Qtz phyllite		Serpentinite	?
Formasi Tarap Greenschist, epidote-amphibolite, amphibolite[2]	Chl-Ep phyllite Grf phyllite Ms-Bio phyllite	Orto-amphibolite Hb schist Act schist Meta-granite		241±1,09[3]
Luk Ulo Complex Eclogite, blueschist, amphibolite, serpentinite[4,5]	Ep-Gln schist Grt-Ms schist Ms schist	Eclogite Grt-Gln schist Grt amphibolite Amphibolite	Serpentinite	110-124[4,6]
Jiwo Hill Blueschist, greenschist, serpentinite[5]	Phyllite	Ep-Gln schist	Serpentinite Calc-silicate schist	98[5]
Meratus Complex Blueschist-amphibolite (high-P), greenschist, serpentinite[5]	Grt-bg-ep-brs schist Ep-brs schist Ep-Gln-Qtz schist Ms schist		Serpentinite	110-119[7]
Bantimala Complex Eclogite, blueschist, greenschist, serpentinite[4,5]	Grt-Gln-Qtz schist Ep-Gln-Qtz schist Grt-Jd-Qtz rock	Eclogite Grt-Gln schist Ep-Gln schist	Serpentinite	113-137[8,9,6]
Barru Complex Amphibolite, greenschist[5]	Grt-Bt-Ms schist		Serpentinite	106±5[8]

[1]Ikhram et al., 2018, [2]Aterta & Hastuti, 2020, [3]Mangga et al., 1994, [4]Miyazaki et al., 1998, [5]Setiawan et al., 2013, [6]Parkinson et al., 1998, [7]Wakita et al., 1998, [8]Wakita et al., 1994, [9]Wakita et al., 1996.

Table 2. Mineral abundance in the thin section.

No.	Lithology	No. Sample	Mineral abundance (%)											Protolith	Facies
			Qz	Plag	Kf	Bio	Musc	Act	Kya	Chl	Epi	Gar	Hb		
1	Muscovite-epidote Schist	PW-9D	++++	-	-	++	++++	-	-	+	+	-	-	Pelitic	Greenschist
2	Muscovite-epidote Schist	PW-4C	++++	-	+	++	+++	-	-	-	-	+	-	Pelitic	Epidote Amphibolite
3	Muscovite-epidote Schist	PW-1A	+++	-	+	-	++	-	-	+	+	-	-	Pelitic	Greenschist
4	Muscovite-epidote Schist	PW-20G	+++	-	-	++	+++	-	-	-	+	+	-	Pelitic	Epidote Amphibolite
5	Muscovite-epidote Schist	PW-8F	+++	-	-	+++	-	-	-	-	++	-	-	Pelitic	Greenschist
6	Muscovite-epidote Schist	PW-4H	+++	+	-	++	+++	-	-	-	+	-	-	Pelitic	Greenschist
7	Greenschist	PW-14G	++	++	-	-	-	++++	-	-	++	-	+	Mafic rock	Epidote Amphibolite
8	Greenschist	PW-12G1	++	+	+	-	-	++++	-	-	+	-	-	Mafic rock	Greenschist
9	Greenschist	PW-4G	++++	-	+	++	+++	-	-	-	-	+	+	Mafic rock	Epidote Amphibolite
10	Greenschist	PW-10J	++++	++	-	+	++	++++	-	-	+	-	-	Mafic rock	Greenschist
11	Biotite-epidote Schist	PW-8B	++++	+	+	++	-	+	-	-	+	-	-	Pelitic	Greenschist
12	Biotite-epidote Schist	PW-3G	++++	+	-	++	-	+	-	-	+	-	-	Pelitic	Greenschist
13	Biotite-epidote Schist	PW-15G	++++	+	+	+++	-	-	+	+	++	-	-	Pelitic	Greenschist
14	Biotite-epidote Schist	PW-6D	-	++++	-	+++	-	-	-	-	+	-	-	Pelitic	Greenschist
15	Quartzite	PW-11E	++++	-	++	-	+++	-	-	+	-	-	-	Quartz arenite	Greenschist
16	Quartzite	PW-12G	++++	-	-	++	-	-	-	-	+	-	-	Quartz arenite	Greenschist
17	Quartzite	PW-9C	++++	-	-	-	-	-	-	-	+	-	-	Quartz arenite	Greenschist
18	Quartzite	PW-8C	++++	-	++	-	+++	-	-	-	-	-	-	Quartz arenite	Greenschist
19	Quartzite	PW-16G	+++	+	-	+++	-	+	+	-	++	-	-	Quartz arenite	Greenschist

Symbol:

-	: absent	+++	: 20% - 30%
+	: less than 10%	++++	: more than 30%
++	: 10% - 20%		

Abbreviation:

Qz	: quartz	Act	: actinolite	Hb	: hornblende
Plag	: plagioclase	Kya	: kyanite	Bio	: biotite
Kf	: k-feldspar	Chl	: chlorite	Musc	: muscovite
Epi	: epidote	Gar	: garnet		

4. Result

The geological mapping conducted indicates that the presence of metamorphic rocks is marked by high topography in the western and eastern parts of the research area. Field observations reveal the presence of schistose foliation and mica mineral lineations in the quartzite lithology. Measurement of foliation planes shows orientations ranging from N330ºE/46º to N328ºE/45º, which align with the Semangko Fault that trends in a northwest-southeast direction.

Field lithology observations and petrographic analysis indicate that the research area consists of four main lithologies: Schist-Biotite-Epidote, Schist – Muscovite - Epidote, Greenschist, and Quartzite. Schist – Biotite - Epidote and Greenschist are distributed in the eastern part of the research area, while Schist-Muscovite-Epidote and Quartzite are found in the western part. The naming of these lithologies is based on the predominant minerals observed in the research area.

Based on the petrographic analysis results, the metamorphic rocks exhibit 10 minerals that constitute the samples. The most abundant minerals within the rocks are quartz, plagioclase, K-feldspar, biotite, muscovite, actinolite, and epidote. These five mineral types are used for the naming of the metamorphic rocks. On the other hand, the other three minerals have a lesser abundance within the rocks, namely chlorite, garnet, and tremolite. The proportion of the mineral assemblages can be seen in **Table 2**.

4.1. Muscovite-Epidote Schist

The outcrop of muscovite-epidote-garnet schist is scattered in the eastern part of the research area and is characterized by a yellowish-brown color (**Figure 2a,d**). This lithology exhibits a foliation orientation of N330ºE/46º. The main minerals that characterize this lithology are quartz+muscovite+epidote. Additionally, a garnet mineral is present with an approximate abundance of 10%. Other minerals such as chlorite+plagioclase+K-feldspar+biotite are also present, with varying mineral sizes ranging from 0.075-0.5 mm (**Figure 3c,g**).

Fig 2. Outcrop of the metamorphic rock in the study area. Most of the metamorphic rock outcrop has a weathering condition. However, the foliation still can be seen in the outcrop.

Based on the petrographic analysis, this lithology is characterized by a heteroblastic texture, which consists of a mixture of granuloblastic and nematoblastic/lepidoblastic minerals. The observed structures within this lithology include porphyroblastic texture, undulation extinction, and subgrain rotation recrystallization (**Figure 4d,e**). The porphyroblastic texture is marked by large-sized quartz grains that are enclosed by smaller-sized garnet grains (PW 4C and PW 20G). In addition, undulation extinction and subgrain rotation recrystallization can also be observed in the quartz grains. The undulation extinction phenomenon indicates the presence of two or more quartz grains within a single mineral.

4.2. Biotite-Epidote Schist

This lithology is located in the northwestern part of the research area and is characterized by yellowish-brown outcrops. It has a foliation orientation of N325ºE/35º. The main index minerals that characterize this lithology are biotite+epidote+quartz+plagioclase. Additionally, k-feldspar and actinolite are also found in some rock samples (**Figure 3b,d**).

In thin section samples, this lithology is characterized by a heteroblastic texture, with a mixture of granoblastic and nematoblastic/lepidoblastic minerals, exhibiting variable degrees of idioblastic to xenoblastic crystalization. Microstructures observed in this sample include poikiloblastic texture, subgrain rotation recrystallization, and undulation extinction in quartz minerals (**Figure 4a**).

4.3. Greenschist

This lithology is located in the northwestern part of the research area and is characterized by a grayish-green outcrop appearance (**Figure 2c,f**). The Greenschist lithology has a foliation orientation of N328ºE/45º and is characterized by the main minerals actinolite and quartz. In addition, several other minerals are also present, such as plagioclase+k-feldspar+epidote+chlorite+muscovite+biotite+hornblende (PW-14G and PW-4G), and garnet (PW-4G) in some thin section samples (**Figure 3e,f**).

The petrographic analysis of this rock reveals a nematoblastic texture with a degree of idioblastic to xenoblastic crystallization. Microstructures observed in this thin section include porphyroblastic, poikiloblastic, subgrain rotation recrystallization, undulation extinction, and decussate (**Figure 4c,f,g**). The porphyroblastic texture is exhibited by the presence of actinolite minerals within the quartz, while the poikiloblastic texture is characterized by feldspar minerals that have undergone corrosion. The decussate texture is observed in the overlapping arrangement of actinolite minerals, resembling a glomeroporphyritic texture in igneous rocks.

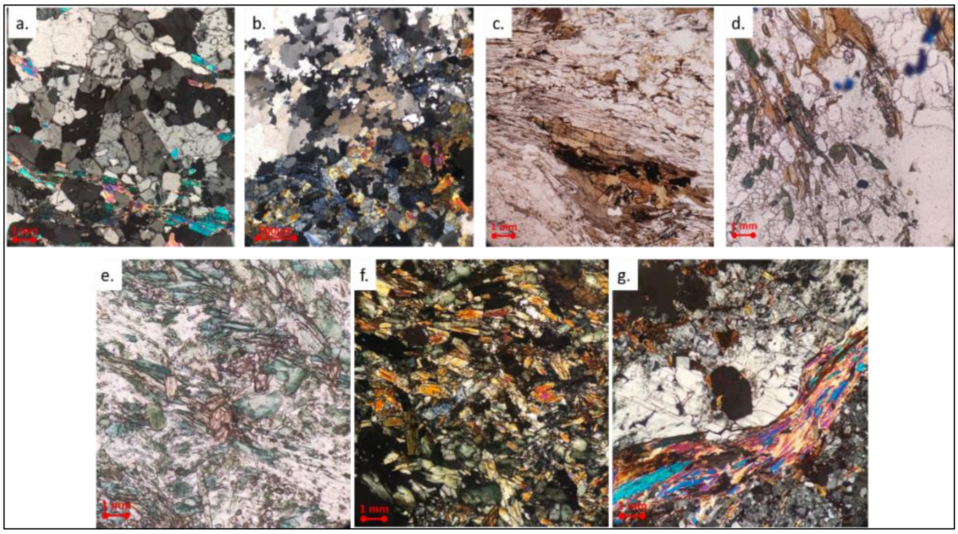


Fig 3. Mineral abundance in metamorphic rocks. (a-g.) Quartz is a dominant mineral and is present in every lithology. It is shown by the granular shape and shows undulate extinction in schist (c-g) and quartzite (a-b). Muscovite and biotite are present as the predominant mica minerals (c-d, g). The appearance of mica minerals is marked by bird's eye texture extinction (g). Not only in schist lithology, but muscovite is also present in Quartzite rock (a). Epidote and chlorite are present together in each rock sample (b,d), and are abundant in Biotite-epidote Schist and Muscovite-epidote Schist (d). Actinolite is present in abundance in Greenschist rocks, followed by tremolite and kyanite (e,f). In addition, the k-feldspar minerals and plagioclase are present in the schist (g). Some k-feldspar minerals exhibit a lamellar texture as a result of internal changes within the mineral.

4.4. Quartzite

The quartzite lithology is located in the western part of the research area and is characterized by yellowish-brown outcrops (**Figure 2b,e**). Generally, quartzite lithology exhibits mica lineation (muscovite and biotite) with an orientation of N317^{o}E/46^{o}. The main minerals that characterize this lithology are quartz+K-feldspar+plagioclase+muscovite+biotite. Additionally, there are also significant amounts of epidote+chlorite+ actinolite minerals (>10%) (**Figure 3a**).

Based on petrographic analysis, the quartzite lithology exhibits a homoblastic texture, characterized by granoblastic quartz grains. However, in some observations, nematoblastic and lepidoblastic textures are still present. The degree of crystallization of the minerals comprising this lithology ranges from idioblastic to xenoblastic, with mineral sizes ranging from 0.025 to 1.375 mm.

In addition, minor structures observed in this sample include poikiloblastic texture, subgrain rotation recrystallization, and bulging recrystallization. Subgrain rotation recrystallization and bulging recrystallization structures can be found in the quartz minerals. Some quartz minerals with subgrain rotation recrystallization structures are characterized by the presence of sutures aligned with the long axis of the quartz mineral and lineation (**Figure 4b,e**). On the other hand, the bulging recrystallization structure is characterized by the presence of quartz overgrowth at the edges of the mineral.

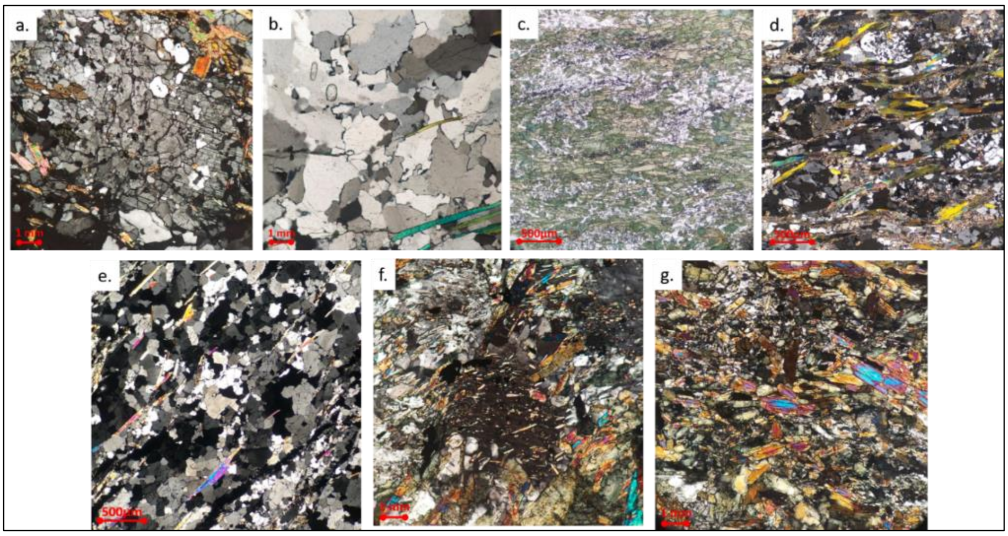


Fig 4. The occurrence of textures and structures in metamorphic rocks. Poikiloblastic can be observed in quartzite rock. It shows the multiple inclusion of tiny minerals in large crystals (a.). Bulging recrystallization shows the former of a new mineral in the large crystal. It can be indicated that the metamorphic has been created at high temperatures (a,e). Subgrain rotation recrystallization is characterized by the long-axis mineral having one direction. The boundary between minerals looks like a suture boundary (b,e). Schistosity foliation can be observed in figures c,d,f, and g. It shows the segregation between platy mineral and granular mineral (g) in biotite-epidote schist and muscovite-epidote schist. (d) However, it shows segregation between the granular mineral (quartz) and prismatic mineral (actinolite) in greenschist (c,g). Decussate texture can be observed in greenschist lithologies (c). Undulose extinction is commonly present in quartz minerals (b). However, some feldspar mineral shows lamellar textures in the sample. Porphyroblastic texture occurs as a large mineral that covers the small mineral in greenschist (f).

5. Discussion

5.1. Metamorphic rock characteristic

This research provides information about the formation of metamorphic rocks in the study area. The measured foliation planes indicate that stratigraphically, the quartzite lithology is older than the other lithologies. This is indicated by the presence of chlorite and epidote minerals in the quartzite lithology, while garnet and kyanite are present in the greenschist lithology, which is considered older.

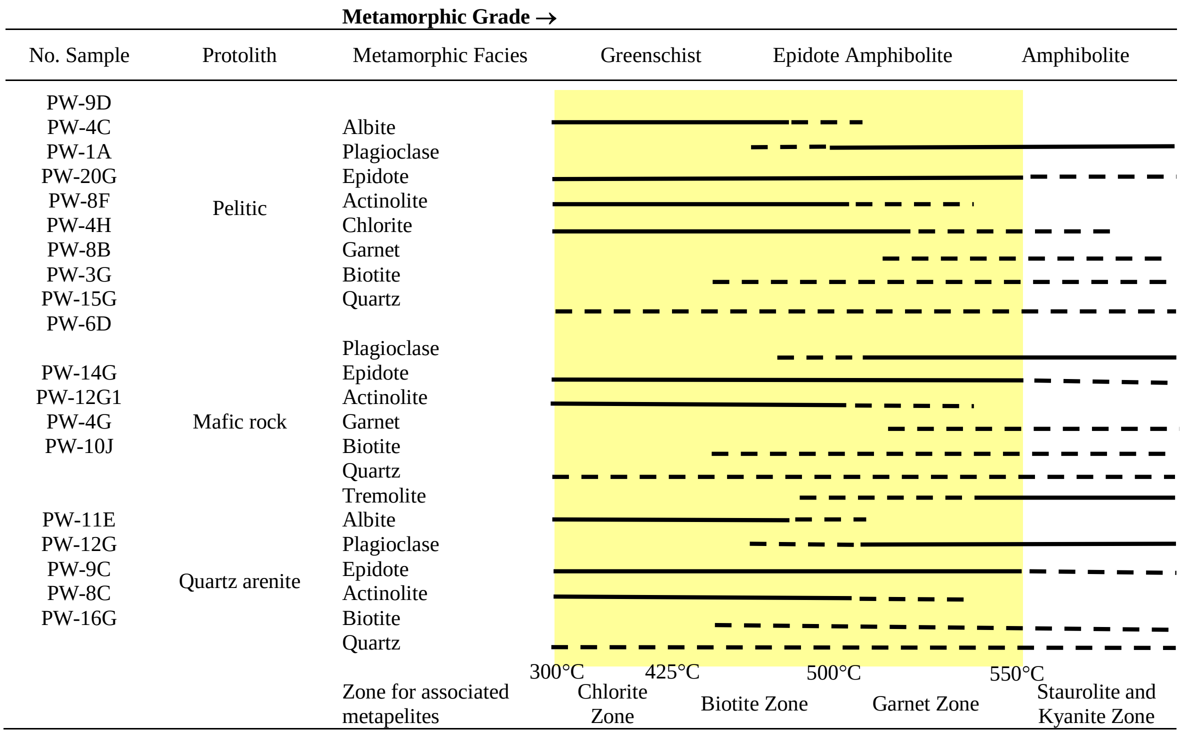
The presence of index minerals in each lithology sample indicates that the metamorphic rocks in the study area originated from pelitic rock, mafic rock, and quartz-feldspathic rock protoliths. The protolith of pelitic rock is characterized by the presence of quartz, feldspar, and mica minerals, as well as a schistose structure in the mica schist lithology (Frost & Frost, 2014). The Pelitic rock itself is a term used to describe claystone that has undergone metamorphism (Frost & Frost, 2014). The protolith of mafic rock is characterized by the presence of actinolite as the main mafic mineral in the greenschist lithology, and the protolith of quartz-feldspathic sedimentary rock is characterized by the presence of quartz minerals (Frost & Frost, 2014) in the quartzite lithology.

The presence of pelitic rock and quartz-feldspathic sandstone protoliths suggests that the metamorphic rocks in the study area originated from the metamorphism of felsic magma, as well as the weathering and erosion of continental crust (Winter, 2014). These protoliths have undergone simultaneous changes in temperature and pressure. The thermal changes are indicated by the presence of the decussate texture in some samples, which is related to thermal transformations within the rock (Passchier & Trouw, 2005). Additionally, the pressure changes in the rock samples are evident through the presence of foliation and lineation, particularly observed in the mica schists and quartzite lithologies.

In addition to the pelitic and quartz-feldspathic protoliths, the study area also contains mafic rocks. The well-preserved greenschist lithology exhibits a schistose foliation, primarily characterized by the presence of actinolite minerals. The occurrence of mafic igneous protoliths, alongside the other protoliths, adds further interest to the area, as the process of metamorphic rock formation in the study area suggests complex regional conditions. These findings indicate a diverse geological history and provide insights into the intricate processes that have shaped the metamorphic rocks in this region.

The presence of index minerals such as chlorite, epidote, and garnet, as well as the identified protoliths of the metamorphic rocks, indicates that the metamorphic rocks in the study area formed in the chlorite to garnet zone (Winter, 2014). According to Frost & Frost (2014), the variations in index minerals observed in the samples of metamorphic rocks suggest a formation temperature range of 300-550°C (**Table 3**). Although high-temperature minerals were not found in all lithologies, the presence of garnet and kyanite in the mica schist and greenschist lithologies indicates prograde metamorphism in the study area. These findings suggest that the rocks underwent increasing temperatures and pressures during their metamorphic history.

Table 3. The zonation metamorphism shows the temperature of metamorphic rocks.



The determination of facies in the research area refers to the study conducted by Miyashiro (1961). Based on the formed metamorphic zones, from the chlorite zone to the garnet zone, it can be concluded that the metamorphism in the research area occurred within the context of regional orogenic metamorphism (Winter, 2014). The metamorphic rocks formed in this process can have a low to high degree of metamorphism. However, the protolith and index minerals found in the research area indicate that the metamorphic rocks in the research area belong to the Barrovian type with a low to moderate degree of metamorphism. The observable facies types are greenschist and epidote-amphibolite.

The greenschist facies has mafic rock, pelitic rock, and quartz-feldspathic sediment as their protoliths. Based on the determination of the formation temperature of index minerals in each metamorphic lithology, the greenschist facies undergoes an increase in formation temperature from 280 to 500°C. This indicates that the formation of the greenschist facies occurs at a range of low to high degrees of metamorphism. On the other hand, the epidote-amphibolite facies has greenschist and quartz-feldspar sediment as their protoliths, with formation temperatures ranging from 500°C to higher temperatures.

Table 4. The temperature of metamorphic rocks is based on the mineral index in every facies.

Lithology	Mineral	Temperature (°C) 100 200 300 400 500
		Greenschist
Muscovite-epidote Schist	Chlorite	
	Albite	
	Epidote	
Greenschist	Chlorite	
	Epidote	
	Actinolite	
Biotite-epidote Schist	Chlorite	
	Albite	
	Epidote	
	Actinolite	
Quartzite	Chlorite	
	Albite	
	Epidote	
	Actinolite	
		Epidote - Amphibolite
Muscovite-epidote Schist	Plagioclace	
	Epidote	
	Garnet	
Greenschist	Plagioclace	
	Epidote	
	Garnet	
	Tremolite	

5.2. Interpretation of Tectonic Evolution

The presence of two types of crust, oceanic and continental crust, as the main sources of protolith formation, indicates the convergence process that occurred during the formation of the metamorphic rocks in the study area. This can be observed in the garnet porphyroblastic (PW 4C) and subgrain rotation recrystallization (PW 9C) which show elongated crystal axes aligning with the direction of micas. Microstructures such as lineations found in quartzite lithology and the presence of chlorite in the study area suggest that the metamorphism occurred at low degrees of metamorphism.

The subduction activity in Sumatra Island can lead to magmatic and tectonic activities, accompanied by the formation of secondary minerals. The metamorphic rocks in the study area are interpreted as being formed at the plate boundary during the subduction event (Fig. 7), which occurred under low to medium temperature and pressure conditions. This is evidenced by the presence of lineaments in the amphibolite, phyllite, and quartzite samples. In the study area, several mineralization processes are observed, including the presence of iron and manganese ore deposits, which are believed to have a host rock origin from metamorphic rocks.

The tectonic evolution model proposed by Advokaat et al. (2018) states that the southern part of Sumatra was formed through the subduction process of the West Sumatra microcontinental arc and the Woyla intra-oceanic block. Research on metamorphic rocks in the southern part of Sumatra indicates that these metamorphic rocks originated from the West Sumatra microcontinental arc. However, the discovered metamorphic facies do not show evidence of subduction, such as the presence of blueschist and eclogite.

The presence of greenschist, along with mica schist and quartzite, indicates the involvement of both oceanic and continental crust materials. This suggests the emplacement of the oceanic crust or subduction of the oceanic crust beneath the continental crust, leading to metamorphism in the underlying rocks. This supports the allochthonous theory of metamorphic rocks proposed by previous researchers (Barber & Crow, 2005a). Additionally, the orogenic events that occurred during the late Cretaceous to Early Tertiary, as well as the reverse faulting and fault-thrusting-fold processes, have influenced the metamorphism. Subsequently, the rocks were uplifted, leading to the formation of an accretion prism that subjected them to metamorphic conditions characterized by lower temperature and pressure, resulting in retrograde metamorphism (Mangga et al., 1994).

6. Conclusion

Based on the analysis conducted, this study concludes that:

The metamorphic rocks in the study area are in the greenschist to epidote-amphibolite facies, with formation temperatures ranging from 280°C to 550°C.

The metamorphic rocks in the study area formed during the orogenic process that occurred in the Mesozoic era, when the intra-oceanic Woyla plate and West Sumatra terrain underwent subduction.

Furthermore, further research is needed to determine the absolute age of the metamorphic rocks and the characteristics of the terrain that formed the metamorphic rocks in Lampung.

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References

Advokaat, E. L., Bongers, M. L. M., Rudyawan, A., BouDagher-Fadel, M. K., Langereis, C. G., & van Hinsbergen, D. J. J. (2018). Early Cretaceous origin of the Woyla Arc (Sumatra, Indonesia) on the Australian plate. *Earth and Planetary Science Letters*, *498*, 348–361. https://doi.org/10.1016/j.epsl.2018.07.001

Alditian. (2022). *GEOLOGI DAERAH PAGELARAN UTARA DAN SEKITARNYA, KABUPATEN PRINGSEWU, PROVINSI LAMPUNG TUGAS AKHIR*. Institut Teknologi Sumatera.

Amin, T. C., Sidarto, Santosa, S., & Gunawan, W. (1993). *Geological Map of the Kotaagunf Quadrangle, Sumatera*.

Amin, T. C., Sidarto, Santosa, S., & Gunawan, W. (1994). *Geology of the Kotaagung Quadrangle, Sumatera*.

Aterta, T. S., & Hastuti, E. W. D. (2020). *FASIES METAMORFISME KOMPLEK GARBA, DAERAH SINAR MULYO, OGAN KOMERING ULU SELATAN, SUMATERA SELATAN*. Universitas Sriwijaya.

Barber, A. J., & Crow, M. J. (2005a). Pre-Tertiary Stratigraphy. In A. J. Barber, M. J. Crow, & J. S. Milsom (Eds.), *Sumatra: Geology, Resources, and Tectonic Evolution* (Vol. 31, pp. 24–53). The Geological Society. http://mem.lyellcollection.org/

Barber, A. J., & Crow, M. J. (2005b). Structure and structural history. In A.J. Barber, M.J. Crow, & J.S. Milsom (Eds.), *Sumatra: Geology, Resources, and Tectonic Evolution* (pp. 175–233). The Geological Society. http://mem.lyellcollection.org/

Barber, A. J., Crow, M. J., & De Smet, M. E. M. (2005). Tectonic Evolution. In A.J. Barber, M.J. Crow, & J.S. Milsom (Eds.), *Sumatra: Geology, Resources, and Tectonic Evolution* (pp. 234–258). The Geological Society. http://mem.lyellcollection.org/

De Coster, G. L. (1974). The Geology of The Central and South Sumatra Basins. *Indonesian Petroleum Association*, 77–110.

Dewinta, V. (2021). *GEOLOGI DAERAH WATES DAN SEKITARNYA, KABUPATEN PRINGSEWU, LAMPUNG*. Institut Teknologi Sumatera.

Frost, B. R., & Frost, C. D. (Carol D. (2014). *Essentials of igneous and metamorphic petrology*. Cambridge University Press.

Hall, R. (2009). The Eurasian SE Asian margin is a modern example of an accretionary orogen. *Geological Society Special Publication*, *318*, 351–372. https://doi.org/10.1144/SP318.13

Hendrawan, R. N., & et al. (2022). *Geological Structure Analysis Approach to Control the Distribution of Manganese in Gunungkasih Area, Tanggamus Regency, Lampung Province*. https://drive.google.com/drive/u/2/folders/1hj-rQq2GsdHI-6bBV11DUVcxXn-CGGT7

Ikhram, R., Hardiyono, A., Syafri, I., & Rosana, M. F. (2018). Petrological Study of Metamorphic Rocks in Melangè Complex of Ciletuh Area, West Java, Indonesia. *International Journal of Earth Sciences and Engineering*, *11*(02), 146–152. https://doi.org/10.21276/ijee.2018.11.0208

Mangga, S. A., Amiruddin, Suwarti, T., Gafoer, S., Tobing, S., Sidarto, & Andra, A. (1994). *Geologi Lembar Tanjungkarang, Sumatera*.

Mangga, S. A., Amirudin, Suwarti, T., Gafoer, S., & Sidarto. (1993). *PETA GEOLOGI LEMBAR TANJUNG KARANG, SUMATERA*.

Mccourt, W. J., Crow, M. J., Cobbing, E. J., & Amin, T. C. (1996). Mesozoic and Cenozoic plutonic evolution of SE Asia: evidence from Sumatra, Indonesia. In R. Hall & D. Blundell (Eds.), *Tectonic Evolution of Southeast Asia* (pp. 321–335). Geological Society. http://sp.lyellcollection.org/

Metcalfe, I. (2017). Tectonic evolution of Sundaland. *Bulletin of the Geological Society of Malaysia*, *63*, 27–60. https://doi.org/10.7186/bgsm63201702

Miyashiro, A. (1961). Evolution of Metamorphic Belts. *Journal of Petrology*, *2*, 277–311. http://petrology.oxfordjournals.org/

Miyazaki, K., Sopaheluwakan, J., Zulkarnain, I., & Akita, K. (1998). A jadeite-quartz-glaucophane rock from Karangsambung, Central Java, Indonesia. *The Island Arc*, *7*, 223–230.

Natalia, H. C., Widiatama, A. J., Hendrawan, R. N., Christi, D. A. G., Kemala, A. T., & Nahar, R. N. F. A. (2022). *Distribution of Manganese Ore Deposit in Sukaagung Village, Tanggamus Regency, Lampung*.

Natawidjaja, D. H. (2018). Updating active fault maps and slip rates along the Sumatran Fault Zone, Indonesia. *IOP Conference Series: Earth and Environmental Science*, *118*(1). https://doi.org/10.1088/1755-1315/118/1/012001

Parkinson, C. D., Miyazaki, K., Wakita, K., Barber, A. J., & Carswell, D. A. (1998). An overview and tectonic synthesis of the pre-Tertiary very-high-pressure metamorphic and associated rocks of Java, Sulawesi, and Kalimantan, Indonesia. *The Island Arc*, *7,* 184–200.

Passchier, C. W., & Trouw, R. A. J. (2005). Microtectonics. In *Microtectonics*. Springer Berlin Heidelberg. https://doi.org/10.1007/3-540-29359-0

Prasetyo, S. A. (2023). *GEOLOGI DAERAH TAMBAHREJO DAN SEKITARNYA, KABUPATEN PRINGSEWU, PROVINSI LAMPUNG*. Institut Teknologi Sumatera.

Setiawan, N. I., Osanai, Y., & Prasetyadi, C. (2013). *Prosiding Seminar Nasional Kebumian Ke-6 Teknik Geologi Universitas Gadjah Mada*.

Soesilo, J., Schenk, V., Suparka, E., & Idham Abdullah, C. (2015). THE MESOZOIC TECTONIC SETTING OF SE SUNDALAND IS BASED ON METAMORPHIC EVOLUTION. *INDONESIAN PETROLEUM ASSOCIATION*.

Subandrio, A. M. (2007). *INDONESIAN BANDED IRON FORMATION (BIF): A CONTROVERSIAL IN AGE AND TECTONIC SETTING OF BIF MINERALIZATION IN TANGGAMUS AREA – LAMPUNG, SOUTH SUMATRA*.

Susilohadi. (2019). *Atlas Seismik Refleksi Dangkal Selat Sunda Timur Laut dan Teluk Lampung* (L. Arifin, M. Hanafi, D. Kusnida, & R. Rahardiawan, Eds.). Pusat Penelitian dan Pengembangan Geologi Kelautan. www.mgi.esdm.go.id

Wakita, K., Miyazaki, K., Zulkarnain, I., Sopaheluwakan, J., & Sanyoto, P. (1998). Tectonic implications of new age data for the Meratus Complex of south Kalimantan, Indonesia. *Island Arc*, *7*(1–2), 202–222. https://doi.org/10.1046/J.1440-1738.1998.00163.X

Wakita, K., Munasri, Sopaheluwakan, J., Zulkarnain, I., & Mlyazaki, K. (1994). Early Cretaceous tectonic events implied the time lag between the age of the radiolarian chert and its metamorphic basement in the Bantimala area, South Sulawesi, Indonesia. *Island Arc*, *3*(2), 90–102. https://doi.org/10.1111/J.1440-1738.1994.TB00097.X

Wakita, K., Sopaheluwakan, J., Miyazaki, K., Zulkarnain, I., & Munasri. (1996). Tectonic evolution of the Bantimala Complex, South Sulawesi, Indonesia. *Geological Society Special Publication*, *106*, 353–364. https://doi.org/10.1144/GSL.SP.1996.106.01.23

Winter, J. D. (2014). *Principles of igneous and metamorphic Petrology* (Second). Pearson.