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Petrological Characteristic and Whole Rock Geochemistry of Metamorphic Rocks in Melangè Complex of Ciletuh Area, West Java, Indonesia

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Abstract*— Melangè Complex of Ciletuh Area, West Java, Indonesia is located at 106 ° 23 '38.9 "- 106 ° 25' 27.6" E and 7 ° 14 '27.6 "- 7 ° 12' 46.2" S. This area has unique geological features where the Early Cenozoic uplifted subduction rocks such as ophiolites and metamorphic rocks are exposed. This study aimed to determine the condition of the stratigraphic position and geological structure of metamorphic rock unit in the field, to find out the metamorphic facies and their evolution, to know the parental rocks (protoliths) of metamorphic rocks, and to interpret tectonic environments for the formation of metamorphic rocks based on stratigraphy, geological structure, petrography, and geochemistry. Study of literatures, geological mapping, petrology and geochemical analyses were used as methods of this research. The entire analysis is combined as a guidance in interpretation of petro-tectonic environment. Distribution of metamorphic rock outcrops found in several places, such as, Citisuk River, Cikopo River and Cikarikil River. Based on petrography analysis, metamorphic rocks types consist of schistose amphibolite, various type of greenschist, phyllite and quartzite. The protolith of metamorphic rocks in Ciletuh is quite diverse, namely metasediments such as pelitic, psammitic, calc-silicate sediment, and meta-igneous such as gabbro and basalt. The presence of epidote, chlorite, and calcite in schistose amphibolite show retrograde metamorphism process in lower temperature-pressures condition. The occurance of quartz and calcite vein in several samples was shown as an indication of hydrothermal alteration. Based on geochemical characteristics, the result showed that sedimentary source of metasedimentary rocks were derived from the volcanic arc environment. While, metabasalt rocks were originated from the Island Arc tectonic environment. According to the association, these metamorphic rocks were formed by regional metamorphism, as the result of subduction process and orogenic event. Thus, retrograde metamorphism indicates the lifting or accretion process that caused by subsecuent tectonic activity.

***Keywords*— Ciletuh; metamorphic rocks; petrography; geochemsitry.**

I. INTRODUCTION

Ciletuh Area is known as particular and complex geological phenomena. Melange Complex in Ciletuh Area, West Java, Indonesia, is located at 106 ° 23 '38.9 "- 106 ° 25' 27.6" E and 7 ° 14 '27.6 "- 7 ° 12' 46.2" S (Fig.1). Along with Luk Ulo and Meratus, Ciletuh was considered formed in the southernmost margin of Cretaceous Sundaland subduction system as tectonic mélanges based on the observation of the exposed rocks and their structural configuration [1]. This complex is formed by a complicated geological process of subduction, abduction and a combination of collision between plates and back arc thrust complex [2]. Jampang and Balekambang Geological Map Sheet classified these rocks complex into three units of Pre-Tertiary rock, namely Pasir Luhur, Gunung Beas, and Citirem Formation. The outcrops seem chaotic and mixed up. These group of rocks is called mélange [3]. In this area, melange complex is composed by the group of ultramafic rocks (ophiolite relatives), metamorphic rocks, deep ocean and continental sourced sedimentary rock. All these rocks were found as blocks of various size in the matrix of shale (scally-clay). Moreover the relationship among all of the rock units is a tectonic contact.

However, the detail information regarding these particular rocks especially Ciletuh's metamorphic rocks, is relatively limited. Therefore, in order to complete Indonesia's tectonic puzzle pieces, the author will examine the metamorphic rocks in Ciletuh area. The discussion in this study will focus on the distribution of outcrops, the kinds, and types of metamorphic rocks, the degree of metamorphism, rock origin (protolith), geochemistry and petrotectonic interpretation of metamorphic rocks in the area.

Group of metamorphic rocks in the melange complex of Ciletuh first mentioned by [2], concerning the status of the complex melange. Greenish serpentinite can be recognized in Tegal Pamidangan, Mount Beas, Citisuk River, and Tegal Cikepuh River Belt in the central part of the region Ciletuh.

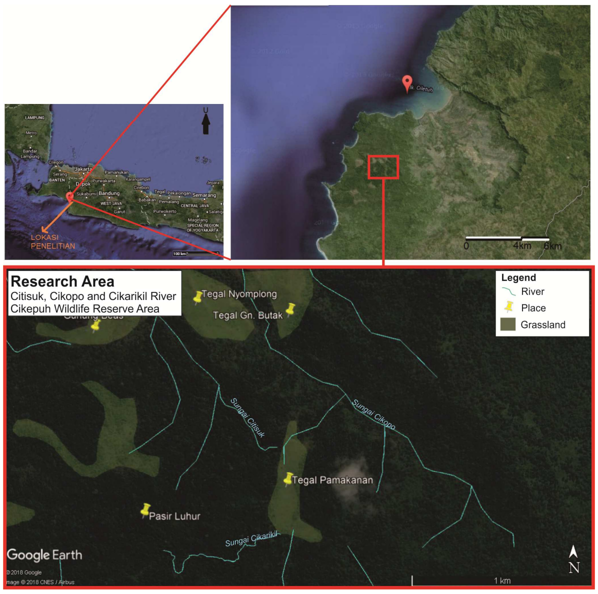

Fig. 1 Index map of research area (Melange Complex), marked by the red square

These rocks are usually found near the fault contact. Serpentinized peridotites are still visible in Tegal Sabuk. It was therefore considered that this serpentinite derived from peridotite due to the hydration process in the oceanic crust. The outcrop in some places near Koneng Hideung area is a hard white quartzite outcrops, fine to medium granurality. Other outcrops also visible in Citisuk River. It is characterized by the presence of quartz veins. The same outcrops also found in Citisuk River. It is characterized by the presence of quartz veins. Dark gray well foliated phyllites are noticed at Badak mountain. Quartzite containing glauphane, also the presence of epidote amphibolite and metamafic epidote crossite (basaltic protolith). While, eclogite still hasn't been found in this area [4].

According to research by the The Indonesian Institute of Sciences (LIPI) [5], Ciletuh bedrock is formed in the accretion system with a movement from the north to the south. By 2015, a geological research team of Padjadjaran University [6] have conducted geological field observations in this region. From these observations it is known that the distribution of metamorphic rocks are random and found separately, but some are continuous along the drainage area. Type of metamorphic rock is consisting of amphibolite, amphibolite schist, greenschist, phyllite and quartzite. Outcrops of metamorphic rocks are situated on the side and the floor of the river. The rivers that expose the metamorphic rocks are Citisuk River, Cibatununggul River, the stream in the northern and southwestern Tegal Pamakanan (Cikarikil River), and the stream on the western Pasir Luhur hill. However, at that time, the research team did not find the presence of blueschist/ glauphane schist, as mentioned in previous studies. The metamorphic rocks indicate low-grade metamorphism in the greenschist-facies. The protolith of metamorphic rocks are suggested from pelitic, ultramafic, and quartz-rich rocks. Present study did not recognize the blueschist or eclogites-facies rocks which indicates high-pressure and low-temperature metamorphism in the subduction system [7].

However, in low to medium grade metamorphic terranes that have experienced multiple stages of metamorphism, distinguishing between, and dating, the different metamorphic events can be challenging. Difficulties mainly derive from the significant mineral, compositional and microstructural inheritance preserved in the samples at relatively low temperatures [8].

II. Material and Method

The rocks samples, the coordinates of the location as well as the foliation direction trend were taken during the field observation (mapping process). This process delivered sample location and foliation trend of metamorphic rocks. Petrographic analysis was conducted by using a polarization microscope. Thin section was made on the 68 units of samples consisting of amphibolite schists, greenschists, and phyllites.

Geochemistry data were collected from laboratory tests using XRF (X-Ray Flourence) and ICP-MS on 2 units of amphibolite schist and 11 units of greenschist samples. The results obtained from the geochemical analysis includes the classification of types of rocks and estimation of tectonic environment. The ACF diagram is used to determine the protolith. The A/NK vs. A/CNK is used to discriminate metaluminous, peraluminous and peralkaline compositions [9] . The FMW Weathering Index diagram [10] represents sources of mafic, felsic igneous rock sources and weathered rocks. The concentration pattern of REE and Trace elements in the sample is included in the spider diagram normalized to chondrite according to [11]. The TiO_2-MnO-P_2O_5 diagram [12] is used for tectonic environment discrimination. Pressure-Temperature pseudosections were calculated with the PERPLE_X computer program package.

III. Results and Discussion

A. *Distribution of Metamorphic Rocks in Ciletuh Area Text Font of Entire Document*

The location that expose metamorphic rocks are Citisuk River, Cikopo River and Cikarikil River in the southwestern of Tegal Pamakanan. The following are the description of each river :

1) Cikopo River - Metamorphic rocks on the Cikopo River are exposed along the river with a maximum outcrop of 3-4 meters along 750 meters. The main direction of the foliation is northwest-southeast, while in the middle of the river path, this direction changes to northeast – southwest.

In the north, which is the lower part of the river, the distribution of metamorphic rocks is bordered by contact with the serpentinite. Whereas in the southern of the upstream part, there is also a similar finding that is shear zone contact between metamorphic rocks and serpentinite which both undergo brecciation. The serpentinite body lies tectonically on top of the schist with a position of N 360ºE / 30º. Generally, approximately the contact or serpentinite base, rocks show strong slickensides. Some serpentinite outcrops that have foliation structure were also found in some places.

In addition, in the southern part, a scally clay outcrop has intensive slickensides with the dominance direction of N 115º E / 35º.

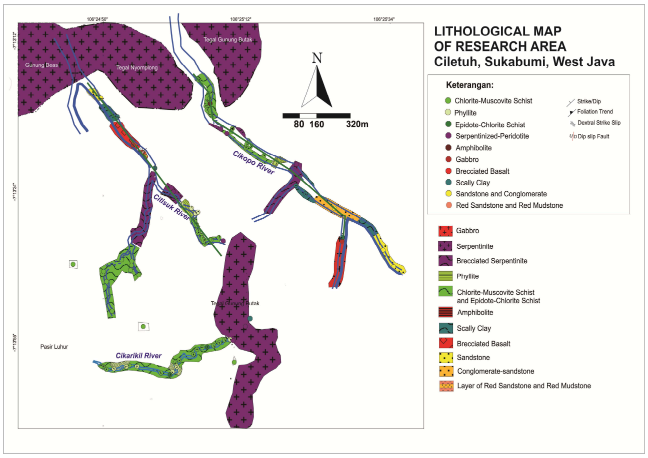

Fig. 2 Lithological Map of Each River

2) Citisuk River: the characteristics of metamorphic rocks on this river are well-developed foliation, composed of green minerals such as chlorite and epidote. It also contains mica, quartz and plagioclase. The direction of foliation formed on the two outcrops is very different, that is northwest-southeast in the downstream and southwestern in the upstream part. However the direction of dipping foliation is relatively the same, which is to the east. This change in direction is estimated because of folds and faults. Reconstruction of the foliation direction shows the existence of geological structures that developed in the research area. The outcrop conditions are relatively fresh, where only some small parts have been oxidized. Metamorphic rocks in this river have been deformated. It was seen from the intensive joints in the body of the rock. Some of them have been filled with other minerals such as quartz, calcite and oxide minerals. The peridotite outcrop in this river has a brecciation structure. It has the similar components and matrices. Shear zone contacts are also found between metamorphic rocks and younger sandstones. In this case, overlying sandstones are not aligned with metamorphic rocks. Evidence of the geological structure was also found in the form of a fault plane on the sandstone outcrop.

3) Cikarikil River: the upstream of Cikarikil River is in the southwest of Tegal Pamakanan, crosses the southern part of Tegal Pamakanan, then continue to the Cikepuh River. Along the headwaters of the river there is a filthy grayish outcrop. The foliation is developed well. The rocks shows a pelitic palimset, the more upstream the more layers of quartzite were found. Some outcrops have experienced strong weathering. These rocks have been exposed to strong deformation. It was seen from the growing number of joints, some of them have been filled with quartz and calcite. The direction of foliation of metamorphic rocks is relatively north-south and northeast-southwest. Composite minerals include quartz, muscovite and chlorite.

Fig. 3 Condition of outcrop in northern and south western of Tegal Pamakanan (A) & (B) Photo of greenschist at Citisuk River (C) Greenschist outcrop at Tegal Pamakanan northern rivers; (D) Photo of phyllite with layers of quartzite outcrops.

B. *Geological* Structure Reconstruction

In this Metamorphic Units, an intensive joint is only measured in two locations. The measurement was taken around Pasir Luhur (the middle part of the study area) in greenschist and phyllite. There are three dominant directions of the joints, namely 90º – 130º, 20º – 40º, dan 160º – 170º North to East. There are two systems of stress, namely North - South extensional stress and Northwest - Southeast – compression stress. The location that expose metamorphic rocks are Citisuk River, Cikopo River and Cikarikil River in the southwestern of Tegal Pamakanan.

There are several fault system in this area, which are reverse and oblique faults with northwest-southeast and northeast-southwest dominant direction. there are three main foliation directions, namely N 355ºE, N 340ºE, or northwest southeast and N 250ºE or northeast-southwest. The geological cross section of each river shows that these directions form anticline and syncline fold, most of which lie northward.

C. *Petrological* and Petrogenetic Analysis

1) Greenschist: Thin section of greenschist samples are taken from Citisuk River, Cikopo River and Cikarikil River. Some samples have fresh surfaces showing a silky lustre, due to the high modal contents of muscovite. In outcrop but also in handsized specimens, a well-developed schistosity, pervasive folding, and crenulation cleavage can be observed. The schistosity is defined by the preferred orientation of phyllosilicates and quartz

Greenschist in the study area can be divided into several types based on the composition of the constituent minerals, namely Muscovite Schist, Muscovite-Chlorite-Epidote Schist, Chlorite-Muscovite-Epidote Schist, Epidote-Chlorite-Muscovite Schist, Albite-Muscovite-Chlorite Schist, Albite-Epidote-Chlorite-Calcite Schist, Calcite-Chlorite-Muscovite Schist, Calcite-Chlorite-Epidote Schist

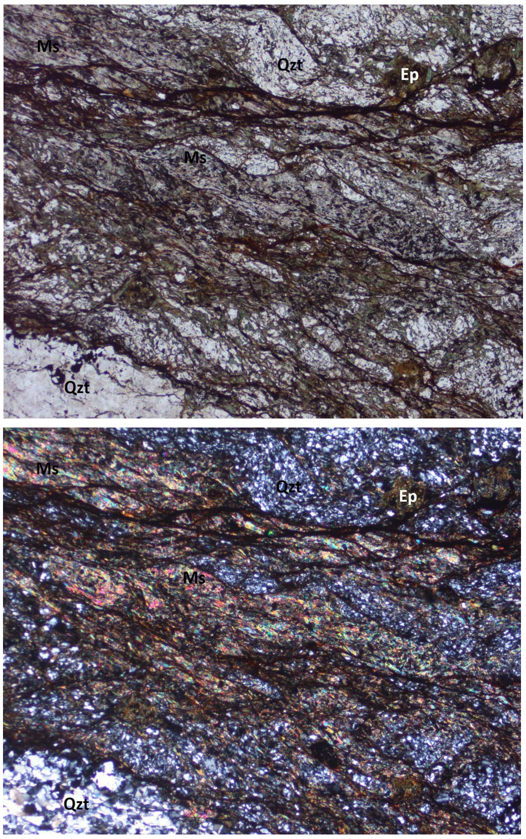

Fig. 4 Microscopic Photography of Muscovite Epidote Schist (Top: Plane Polarised Light, Below: Cross Polarised Light)

Muscovite-Chlorite-Epidote Schist are characterized by white with layers of dark brown-black in plane polarised light, grayish white mostly brownish in cross polarised light, partially oxidized so that there is a brownish-red color, Microscopic photograph of thin section RIM 1-3 can be seen in Fig. 4. They have spaced schistosity and two mineralogically distinct domains: phyllosilicate-rich (white mica ± chlorite) and quartz + feldspar-rich ones. Micro-folding is visible at the hinge points of highly folded phyllosilicate-rich domains. Epidote occur in both domains, but are slightly more concentrated in the phyllosilicate-rich domain. Some samples display cleavage domains defined by phyllosilicates and quartz + feldspar + white-mica layers (microlithons). In the cleavage domains, elongated fibrous (although sometimes clustered) chlorite occurs accompanied by fine-grained white mica. Quartz grains dominate in the microlithons, showing a grain shape preferred orientation being oblique to the foliation, but also minor amounts of feldspar, fine-grained white mica and chlorite. Larger grains of dynamically recrystallized quartz lacking the preferred orientation form several aggregates throughout thin sections and those are usually surrounded by elongated fibrous chlorite. Among predominately finegrained samples, medium-grained (psammitic) and less-homogeneous samples also occur, which are characterized by coarser grains of quartz and feldspars. Such samples display a spaced foliation with white mica + chlorite + epidote, quartz + feldspar + white mica + chlorite, and quartz-rich domains. Minerals in quartz + feldspar + white mica + chlorite domains are equantly finegrained. The quartz-rich domain is defined by quartz aggregates and veins accompanied by clusters of large, fibrous chlorite. Muscovite-rich Schist are estimated originate from pelitic in this case the element K and Al as the clay minerals transformed into muscovite due to metamorphism.

Albite – Epidote – Chlorite - Muscovite Schist are characterized by greenish-white with some layer of blackish brown in plane polarised light, gray with a whitish layer of yellowish brown color in cross polarised light, pophiroblastic texture, lepidoblastic crystal shape, coarse to medium grain size, basaltic palimset. Constituent minerals are albite, epidote, chlorite, fine grained hornblende, opaque minerals found within porphiroblast, some minerals have grains shape, at 100x magnification can be seen that chlorite is foliated with opaque. The edge of some plagioclase looks transformed into epidote. Hornblende has pale brown color, with some opaque mineral inclusions, and altered into chlorite at the rim part. Epidotes are spreaded in the form of granules, sized fine to coarse. Some of which appear to originate from plagioclase alteration, partially bound with quartzite. Microscopically, the foliation structure is not clearly visible. Calcite is present in separate granules, some of which are present as veins and fill the pore (secondary). Based on its mineral group estimated that these rocks originated from sedimentary protolith or fine silica-alkali-calsic sediment as greywake .

Calcite-Chlorite-Epidote Schist are characterized by light brown with layers of dark brown-black in plane polarised light, blackish-brown with cream-brown colour in cross polarised light. Thera are separation of two types of mineralogy domain that looks like "layers", namely phyllosilicate (chlorite) which binds to epidote granules layers and calcite + quartz + feldspar layers. Calcite shows a monoclinic texture, some occure as veins that cut foliation (secondary calcite). Microstructure is seen clearly in the thin section in the presence of microfault in the foliate fold or crenulation. Thus the rock formation is divided four stages, namely, stage diagenesis, metamorphism stage and stage hydrothermal alteration, and weathering and oxidation stages.

Greenschist in Ciletuh Melange Complex formed in the greenschist to epidote amphibolite facies that is low to medium grade metamorphic. In general, the metamorphic rocks derived from rocs of different origins, those are pelitic (clay-rich), psammitic (feldspato-silica rich), calc-silicate (carbonate rich) and basic (basaltic igneous rock).

2) Phyllite: Thin section of phyllites are taken from the outcrop samples located at the site Citisuk River and River Tegal Pamakanan. They are characterized by white color with a slight brownish streaks in plane polarised light, gray with white layer in cross polarised light, foliation structure is less clearly visible than schist, the grain size is fine to very fine, some part shows porphiroblastic texture, the minerals contained such quartz, small amount of plagioclase, chlorite, opaque minerals, oxides Fe / Ti. Metamorphism that occurs is still relatively low degree can be seen from small amounts of mica mineral (mineral metamorphism results) such as chlorite and muscovite. Some sample has shown zeolites fill-fracturing (veins).

Based on the petrography analysis can be seen these samples have experienced low-grade metamorphism. It is also evident from the sets of minerals in this case the result of metamorphism minerals are present in very small amounts.

3) Amphibolite Schist: Amphibolite in general are characterized by brownish-white color in plane polarised light, gray-whitish with brown spots and beige in cross polarised light. texture has been greatly altered as a result of metamorphism, lepidogranoblastic texture, gneiss foliation with separation between two minelagical domain which are plagioclase + feldspar ± quarzt and hornblend + chlorite + epidote one. Some minerals show cataclastic deformation. Alteration minerals such as epidote and chlorite is found in this sample. Illite is resulted by alteration of plagioclase. Type plagioclase is oligoclase (An 25). Most of plagioclase transformed into epidote, visible at the edge of the mineral body. Tremolite-actinolite hornblende present at the edges as changes due to metamorphism. Chlorite present at the edges of pyroxene and hornblende as changes due to metamorphism. This rock is originated from basalt because it is dominated by plagioclase (> 60%) [13]. There is brecciation texture, which have similar appearance as rock fragments, which are contained chlorite alteration. There is a quartz veins that cut the rock body.

Based on the analysis of several thin sections of amphibolite gabbro samples, almost all indicate the presence of epidote and chlorite minerals the mineral alteration. The presence of epidote due to the release of the elements Ca and the addition of Na elements in plagioclase. Hornblende is present because enrichment elements Na, Fe, and Mg. Chlorite is present as a change of hornblende. Then comes sericite and illite as an alteration of plagioclase.

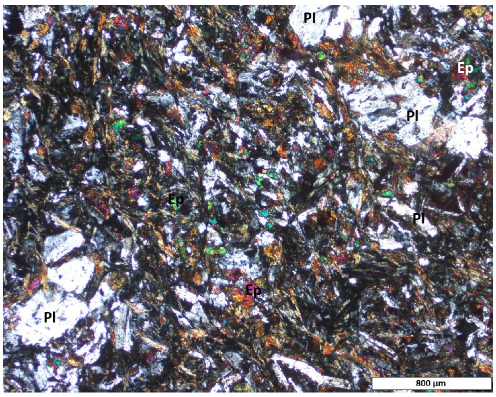

Fig. 5 Cross Polarised Microphotograph of Amphibolite Schist found in Cikopo River (Sample no. RIM 2-18C)

In general, amphibolite on each section consists of hornblende, plagioclase, as well as alteration minerals such as tremolite-actinolite, epidote and chlorite, illite, and opaque minerals. Based on the mineral association, this metamorphic rocks is derived from basaltic protolith or micrograbo (plagioclase-rich). The presence of alteration minerals indicate the process of metamorphism and then there is a decrease in pressure and temperature so it had retrograde metamorphism. Under these conditions, there are 4 phases paragenesis ie, magma crystallization stage, the stage of metamorphism, retrograde metamorphism stage, and the stage of hydrothermal alteration.

D. Whole Rock Geochemistry

Whole rock geochemical data obtained from laboratory tests using XRF (X-Ray Flourence) and ICP-MS methods. The rock samples studied were 7 samples of chlorite muscovite schists of and 3 samples of epidote albite schists.

Based on these values it can be seen that there are differences in the value of the main element and trace elements in the samples taken. This difference can indicate a different type of metamorphic rock protolith in Ciletuh. Samples rich in SiO_2, Al_2O_3, K_2O, Al, K, Ba, Bi, Rb, Th, Tl, Ce are thought to originate from metapelite protolih which is indicated by the presence of quartz + muscovite / sericite minerals. While samples that are rich in CaO, MgO, Fe_2O_3, Ca, Cr, Mg, Na are thought to originate from metapsammite or metagraywek protolith which is indicated by the presence of plagioclase + chlorite + epidote ± quartz ± calcite.

Based on the comparison diagram of SiO_2 vs. Main Elements, there can be seen significant differences between RIM 3-10A, RIM 3-13, RIM 3-17 and RIM 1-18 samples with other samples. The relationship between SiO_2 and CaO and MgO is seen to be negative trend, whereas SiO2 with Al_2O_3 and P_2O_5 shows a trend of positive trend. SiO_2 with K_2O shows a fixed comparison except in the RIM 3-10A, RIM 3-13, RIM 3-17 and RIM 1-18 samples which show a straight comparison.

Based on A/CNK - A/NK diagram [9], some samples are metaluminous, which have lower Al_2O_3 molar proportions than the combination of CaO, Na_2O_3 and K_2O, then some are peraluminous which have higher Al_2O_3 molar than CaO, Na_2O_3 and K_2O combination.

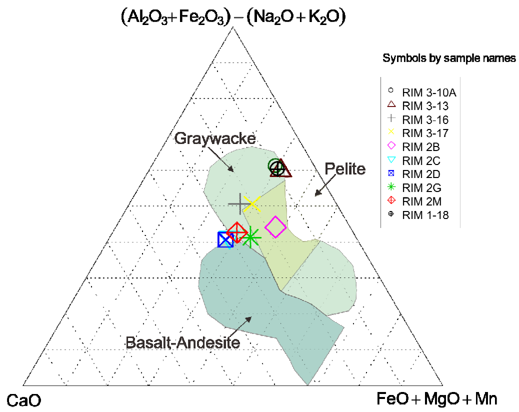

Fig. 6 Plotting on ACF Diagram that show type of protolith

1) Protolith determination based on the ACF Diagram: Based on the results of plotting on the ACF diagram according to [14] with geochemical parameters, namely the ratio of compounds (Al_2O_3 + Fe_2O_3) - (Na_2O + K_2O), FeO + MgO + MnO and CaO and hence the results obtained were RIM 3-10A, RIM 3-13, RIM 3-16 and RIM 1-18, RIM 2G and 2M RIM samples included in the Siliceous Alkali-Calsic

Rocks such as greywacke or volcaniclastic rocks. The RIM 2B sample is included in the slice zone between Siliceous Alkali-Calsic Rocks and Aluminous Rocks like clay-rich. 2D samples are included in the basaltic zone.

2) Determination of Protolith Types Based on FMW Weathering Index Diagram: The FMW Weathering Index diagram [10] represents sources of mafic, felsic igneous rock sources and weathered rocks. *In* the MFW diagram, ploting the sample from the rock is between M - F, where in this case, the mafic rock plot is at the top of the diagram, the plot of felsic rocks in the lower left region, while the middle rock plot is in the middle area. The weathered sample extends in the direction of W and the sample plot is very weathered close to the W vertex. Therefore, M vertices represent the mafic parent rock, vertex F represents the felsic host rock and the vertex W identifies the rate of weathering of the rock.

Based on the diagram, samples of RIM 3-10A, RIM 3-13, and RIM 1-18 numbers show the origin of sedimentary metamorphic rocks because they are outside the zone of fresh igneous rocks, while the other samples come from basaltic igneous rocks because they are near the M axis.

3) Trace Element and Rare Earth Element (REE) Pattern in metamorphic rocks: The concentration pattern of REE elements in the sample is included in the spider diagram normalized to chondrite according to [11]. Based on this diagram, we can see the pattern of distribution of various REE elements. Fluid-rock interactions that destroy plagioclase can deplete Eu, whereas those that produce plagioclase can enrich it [15], [16]. Metapsammite samples show enrichment towards HREE (Tb – Lu Element) with anomalies in Ce that have depletion and Eu experience enrichment that may be influenced by the sedimentation process and plagioclase content in the original sedimentary rocks. Metabasalt samples show enrichment in HREE which might show the influence of oceanic plates during basalt formation.

In the spider diagram normalized to primitive mantle [17], trace element data shows a typical trace element pattern of island arc, with enriched LILE such as Rb, Ba, Pb and K relative to HFSE such as Hf, Zr and Ti. Typical island arc lava is enriched in LILE and LREE (La – Gd Element) but runs out in HFSE, especially in Nb, Ta, and Ti in normalized trace element diagrams [18]. The large Pb gain recorded is inferred to be related to Pb incorporation into abundant sulfide minerals (mostly pyrite)[15].

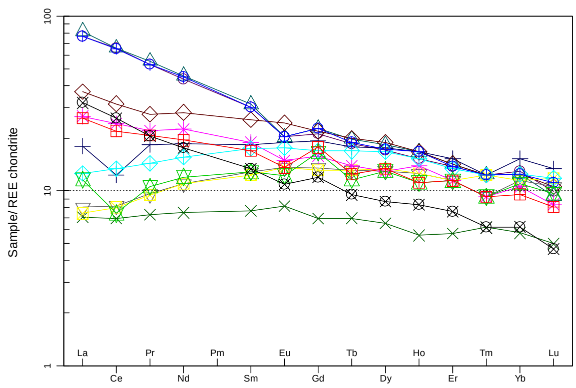

Fig. 7 Distribution of REE in Spider Diagram normalized to Chondrite by [15]

Samples with metapelite properties experience enrichment in element K, whereas in metabasalt samples occur depletion. Evidence from metamorphosed basaltic rocks from the Franciscan Complex suggests that Li is mobile in subduction-related metamorphic fluids, and provides a source of information about the history of multiple fluid sources during metamorphism [19]. Anomalies found in all samples were enrichment of Pb elements. This condition can indicate the interaction process between rocks and water such as sedimentary or hydrothermal sedimentary rocks. Then, Zr - Hf depletion anomaly is caused by contamination of continental crust during subduction processes.

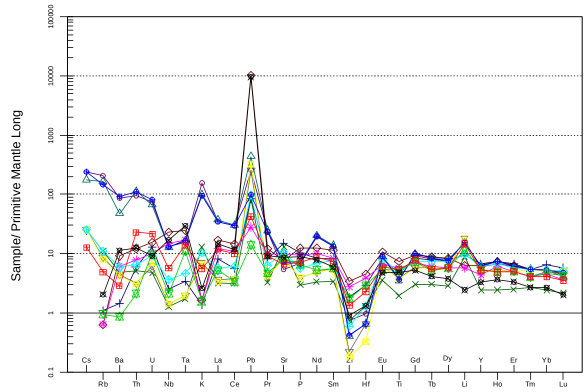

Fig. 8 Trace and Rare Earth Concentration Patterns (Rare Earth Elements / REE) in Metamorphic Rock

4) Tectonic Environment Discrimination based on TiO_2-MnO-P_2O_5 Diagram: Based on the results of plotting on a comparison diagram of the content of TiO_2-MnO-P_2O_5 according to [12], with parameters TiO_2, MnO x 10, and P_2O_5 x 10 on the basalt composition (SiO_2 content 45% - 54%) showed that the metabasalt sample RIM 2, RIM 3-16, and RIM 17 and formed on the Island Arc Tholeiit area, while other samples are not included in the classification because the SiO_2 content is smaller than 45% and greater than 54%.

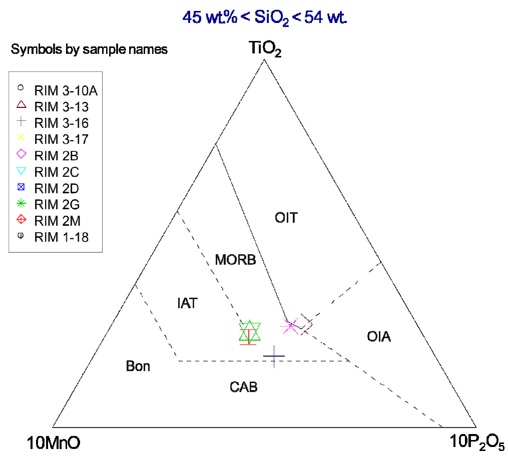

Fig. 9 TiO_2-MnO-P_2O_5 Diagram for Tectonic Enviroment Discrimation

5) Determination of Sediment Sources from Metasedimens based on La-Sc-Th diagram: Chemical composition of the clastic sediments depends mostly on the composition of their source rocks and the intensity of their chemical weathering, but also on the rate of sediment supply, which is somehow governed by tectonics and on textural and mineralogical sorting during transportation and deposition [20]. Based on the plotting of the La-Th-Sc triangle diagram according to [21] for the determination of the tectonic environment of sediment sources, it shows that the source of sediment from the metasediment in Ciletuh comes from the environment associated with the magmatic-arc.

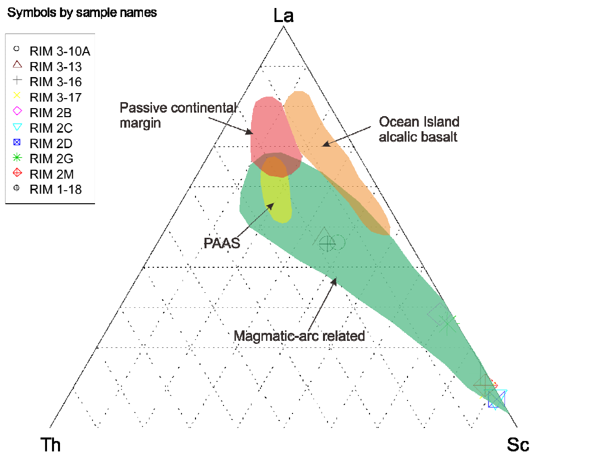

Fig. 10 La-Th-Sc Diagram for Determination of Sediment Sources

6) Pressure-Temperature (P-T) Estimation of Metamorphic Rocks: The identification of relative or absolute changes in P–T conditions during metamorphism is a fundamental step in elucidating the geodynamic processes that have affected a geological terrane [22]. The first computational approach is to use Gibbs free energy minimization to determine the stable phase assemblages ata given P–T condition. The common software packages available for this approach are Perple_X [23].

The P-T pseudosection calculation results in the P-T field for the mineral collection, which is characteristic for low to medium grade metapelite. The samples consist of philosophilicate (chlorite, K white-mica), epidote type zoisite, plagioclase (albite), quartz, and opaque (magnetite, ilmenite).

Chlorite in pseudo-calculations occurs in a fairly wide range. Muscovite and quartz are scattered everywhere throughout the Ciletuh P-T metapelite range. Clinozoisite is present at P-T relatively low (<360°C) compared to zoisite at P-T (360º-610ºC). From the psedosection diagram of Chlorite-Muscovite-Epidote Schist with a collection of Chlorite (Chl) + Muscovite (M) + Epidote Zoisite (zo) + Albite (ab) + microcline (mic) + and quartz (q) shows P-T metapelite range ie 370 - 445ºC temperature and 2 - 3.25 Kbar pressure.

The pseudosection diagram of Albite-Epidote-Muscovite Schist shows that chlorite is quite a wide range, quartz is spread throughout the P-T range, and plagioclase appears at temperatures above 380 º C. Muscovite is present at pressures above 4.25 bar. From the psedosection diagram with a collection of minerals Chlorite (Chl) + Plagioclase (Pl) + Muscovite (M) + Epidote-Zoisite (zo) + Albite (ab) + microcline (mic) + and quartz (q) obtained PT metapsammite ranges that PT specific, namely T: 450ºC and P: 4.25 Kbar.

Amphibolite schist in the Cikopo River show a retromorgrade process, from intermediate degrees such as amphibolite schist (homblenda-plagioclase) and epidote amphibolite schist (epidote-plagioclase-homblende) to a lower degree, such as actinolite-tremolite albite chlorite or talk-chlorite. The two groups of amphibolite schist rocks above originated from basaltic rocks which were thermalized at temperatures around 500° - 600°C and pressure around 5-6 Kbar. The process of metamorphism is interpreted to occur at the subduction zone. Therefore, this metamafic is part of the Indo-Australian oceanic crust that has been subducted since the Cretaceous. As more mentioned degrees of rock are interpreted to be formed by the retromorphism process (T: 300 °-400 ° C at P: <4Kbar).

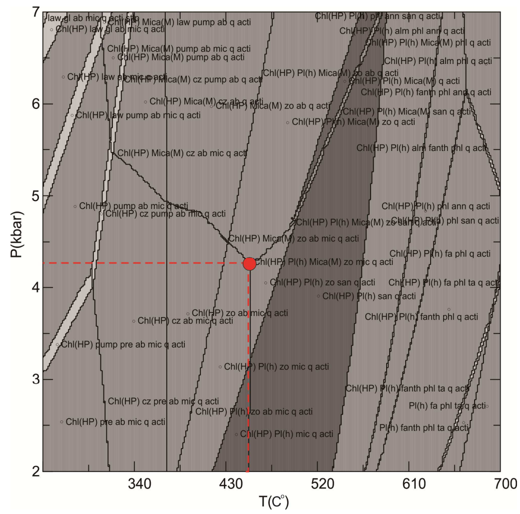

Fig. 11 The Pseudosection for Albite-Epidote-Muscovite Schist shows more specific P-T range, namely T: 450ºC and P: 4.25 Kbar.

E. New Consideration of Tectonic Setting

Then, note also that the protolith of metamorphic rocks is metapelite (clay-rich), metapsammite, metacalcarenit, metabasic and metagabro. It is also supported by the results of geochemical analysis using ACF diagram. The data of the observations observed both in the Citisuk river and on the Cikopo river indicate the relative movement of the base section block from main to cell or relative NW to SE-SW. The microstructure formed by secondary minerals in the form of chlorite or epidote both shows that this structure is formed at low temperatures with the direction of movement interpreted as a result of the subduction of rock in the accretion system [5]. Based on its protolith, this metamorphism affects rocks originating from continental plates (metapelitic, metapsammitic, metacalc arenite) and oceanic plates (metabasic). This indicates that the formation of metamorphic rocks occur at the converging of the two types of crust.

Tectonic Environment Discrimination based on TiO_2-MnO-P_2O_5 Diagram shows that the metabasic are generated in Island Arc environment. This indicates the existence of Intrao-ceanic Subduction Zones where island arcs form on top of older oceanic crust [25]. The unknown oceanic crust is on the outer boundary of the continental plate that is called the Supra-Subduction Zone (SSZ). This SSZ form by a sequence of events in response to changes in tectonic setting from mid-ocean environments to zones of subduction imitation [26].

The subduction process causes the formation of local magmatism and island arc characterized by alteration traces in metamorphic rocks. Some even carry a mineralization process such as the appearance of iron sulfide.

This interpretation leads to a debate about which oceanic plate is on the subducted plate. However, several research mentions probability of this tectonic setting in other areas such as the Meratus tectonic belt. This process can also be related to the existence of Woyla Arc which shows the former oceanic crust in the western part of Sundaland (South East Asia especially Sumatra, Java) [27].

The main problem of Ciletuh's melange tectonic reconstruction is unavailability of radiometric dating information. As mentioned by [28] the age of Ciletuh's gabbro is 56.0 ± 2.3 mya and 50.9 ± 2.1 mya which explain the formation of ophiolite during the Early Eocene. The existence of Island Arc is thought to be the environment of ophiolite formation. Temporary allegations, metamorphism occurred shortly or after the formation of the ophiolite.

Thus, these metamorphic rocks are then accreted together with the presence of oceanic crustal rocks from the island arc base, which formed in Middle Eocene. Along with the accretion process, it is deposited along the sediments that form the Ciletuh Formation. This argument is reinforced by the presence of claystone fragments embedded in schists (on the Citisuk river). Set of reverse fault in Ciletuh Bay show indication of convergence zone between the oceanic crust in the south with an unknown oceanic crust in the north. This is thought to be part of an old accretion prism that gives rise to the mélange [29].

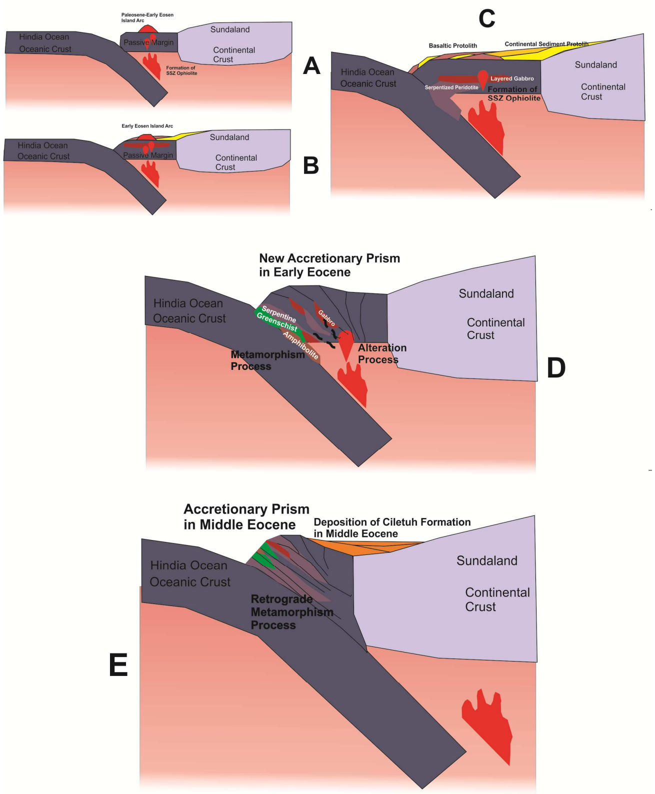

Fig. 12 Illustration of Tectonic Mecanism in Ciletuh (A) Supra-Subduction Zone. This process forms the Island Arc system; (B) Island Arc is active in producing extusive materials such as basalt. Along with sediments sourced from the continent also deposited above passive margin; (C) Formation of ophiolite; (D) The formation of metamorphic rocks and accretion prism; (E) Metamorphic and ophiolite rocks of subduction slabs are uplifted by a reverse fault mechanism.

In addition, interesting facts derived from field observations, in this case shown in the geological cross section. Results positioning outcrops of metamorphic rocks of the ophiolite rocks, then adjusted to the foliation direction can describe that position Schist Unit appears to be flanked by peridotite-serpentinite unit. This can be interpreted as the existence of oceanic crust emplacement or subduction onto continental crust that causes metamorphism in rocks beneath it. Orogenenic events that occurred in the Early Cenozoic and the reverse fault and fault-thrusting-fold [30] also affects the metamorphism. Then, the rock was uplifted and the formation of accretion prism which brings metamorphic conditions with lower temperature and pressure, causing retrograde metamorphism.

IV. Conclusions

Distribution of metamorphic rocks in Melange Complex is random and found separately, but some are continuous along the watershed. Schist in the research area is greenschist and epidote amphibolite schist, foliation can be seen well. Mineral constituent especially chlorite, quartz, most samples contained epidote and actinolite which is characteristic of greenschist facies. Protolith of greenschists which are pelite (clay-rich), psammitic, calc-arenite and basaltic. Schist in the research area has been noticeably affected by the geological structure and hydrothermal alteration because of the veins of quartz and calcite. Phyllites, based on its mineral group estimated that these rocks originated from psammite or sedimentary rocks rich in quartz and plagioclase that experienced low-grade metamorphism on because there is slight of chlorite. Some of them have experienced metamorphism in zeolite facies because there are many clays and foliation are not well developed. On each sample of Amphibolite schist consists of hornblende, plagioclase, as well as alteration minerals in the form of tremolite-actinolite, epidote and chlorite, illite, and opaque minerals. Based on the mineral groups can be interpreted that this metamorphic rocks derived from basalt protolith or leukograbo (plagioclase rich). The presence of alteration minerals indicates the process of metamorphism and then there is a drop in pressure and temperature so that the experience retrograde metamorphism.

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