

Miocene tectonic of the Southeast Arm of Sulawesi, Indonesia: Based on petrology data, geochemistry, and $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology of metamorphic rocks from Rumbia Complex

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Abstract. The Rumbia Complex or the Rumbia Mountains is more popularly referred to as Rumbia Schist Complex, located in the Southern Part of the Southeast Arm of Sulawesi. It is one of the regional metamorphic rock complexes in Sulawesi. This area became popular when the discovery placer gold deposit in Bombana area around Rumbia Mountains, in 2007. This study aims to identify metamorphic rocks of the Rumbia Complex including petrology, geochemistry, and radiometric age dating to determine the evolution of the rock, as well as its relation to the tectonic evolution of the Southeast Arm of Sulawesi. The research methodology includes a geological survey to see the distribution of rock units as well as representative sampling and create a geological map of the Rumbia Complex. Furthermore, thin section analyses with polarization microscope for rock identification, as well as geochemical analysis to obtain Rare Earth Element (REE) using *LA-ICP-MS* to determine rock protoliths. While radiometric age dating used $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology to determine rocks evolution, and the interpretation of geological events in the Rumbia Complex, and or in the Southeast Arm of Sulawesi. The research results showed that Rumbia Mountains is dominated by metamorphic rocks (Mica Schist, Chlorite Schist, and Glaucophane Schist). The result of thin section analysis it is known that some of Glaucophane Schist have undergone retrogradation into Chlorite Schist. While consistent of the Rare Earth Element (REE), it is known that the metamorphic rock protolith of Glaucophane Schist, and Chlorite Schist are "Oceanic Island Basalt" (OIB). Whereas based on radiometric age dating results it is known to have occurred three times large geological events in the Rumbia Complex during Miocene (23 Ma, 20 Ma, and 17 Ma). It is suspected to be related to the amalgamation events of the three microcontinents (Rumbia, Mekongga, and Meluhu Microcontinents) formed the Southeast Arm of Sulawesi as we know today.

Keywords: Miocene, tectonic, metamorphic, $^{40}\text{Ar}/^{39}\text{Ar}$, geochronology, Rumbia, Southeast, Sulawesi, Indonesia



1. Introduction

The Southeast Arm of Sulawesi is the result of three Micro Continent amalgamations, namely Rumbia, Mekongga, and Meluhu Micro Continent [1]. This region composed by a bedrock complexes that characterizes by continental crust, and oceanic crust. Continental crust in this area dominated by metamorphic schist, and metasandstone. While oceanic crust is present as ophiolite, and some have serpentinization [1, 2, 3].

The Rumbia complex is one of the metamorphic rock complexes in Sulawesi. This complex located in the southern part of the Southeast Arm of Sulawesi, arranged by Glaucophane Schist, Chlorite Schist, Mica Schist, and limited Marble (Fig.1) [1, 2].

The Rumbia Complex has recently become very popular, especially among geologists, because of the discovery of an abundance of placer gold deposits in this area [1]. The placer gold deposits were first discovered by local community in the Langkowala Valley in 1997. Langkowala Valley located between the Rumbia Mountains and Mendoke Mountains [1, 2]. Placer gold deposit is suspected to originate from the results of metamorphic and metabasite rock debris from the Rumbia Mountains and Mendoke Mountains [4]. Gold deposits in the Rumbia Complex are orogenic gold deposits type [5], said to be related or overprinting with hydrothermal activity [2].

Before the last few studies, in the Southeast Arm of Sulawesi, it was known as a producer of laterite nickel ores [1]. Especially it the Soroako area which has been exploited since the 1970s by PT. INCO which is currently acquired by PT. VALE. Laterite nickel ores, also abundant at Pomalaa, which was exploited by PT. Aneka Tambang (Persero). The deposit of laterite nickel ore was explored and exploited heavily in the 2000s until today. The widespread presence of laterite nickel ore in the Southeast Arm of Sulawesi, is related to the Ultramafic Rock Formation which is widespread in this region, as a tectonic switch or emplacement [1], [7].

This study focused on large geological events to determine the relationship with the presence of metal minerals or metallogeny paths in the Southeast Arm of Sulawesi. The metallogeny path in the Southeast Arm of Sulawesi is closely related to the large geological event that accompany the presence of ultramafic rocks in this region. It is also an important part in the process of metamorphism that occurred during the Miocene in the Rumbia Complex, and or in the Southeast Arm of Sulawesi. The results of this study explain that the evidence is recorded on metamorphic rocks in the Rumbia Complex, and as a large geological event in the Miocene in the Southeast Arm of Sulawesi.

The Southeast Arm to the East Arm of Sulawesi is the same geological province, composed by metamorphic rocks, and ophiolite that were emplacement during the Oligocene [6].

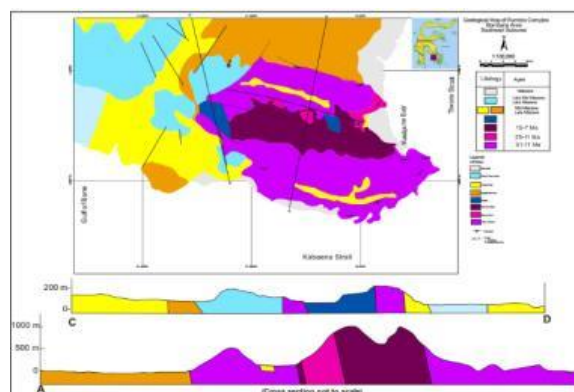


Figure 1. Geological Map of Rumbia schist Complex [1, 2].

2. Research methodology

Research methodology includes (1) geological surveys and rock sampling; (2) Laboratory Analysis includes thin section analysis, geochemical analysis and radiometric age dating. Thin section analysis includes analysis of microstructure and mineralogical evaluation to show the relationship of events or

tectonic regimes with geological age data [6, 7, 8, 9, 10]. Geochemical analysis to determine the geological environment of rock formation [11, 12], as well as its relationship with the metallogeny pathways in the Southeast Arm of Sulawesi. (3) Radiometric age analysis using $^{40}\text{Ar}/^{39}\text{Ar}$ dating method, to determine the geological evolution that occurs in the Rumbia Complex in particular and its implications with the tectonic evolution of the Southeast Arm of Sulawesi [13, 14, 15].

3. Results and Discussion

The results of this study include micro-tectonic data, geochemical data include (major element, trace elements, rare earth elements), and radiometric age data of metamorphic rocks. The details are described in the following sub-sections.

3.1 Thin section analysis

The results of microstructure analysis on metamorphic rocks showed that the Rumbia Complex had experienced compressional and extensional tectonic regimes. This data is found on Glaucophane Schist, Mica Schist as well as Chlorite Schist.

Thin section analysis of mica schist shows the compressional tectonic regimes reflected by the presence of symmetrical crenulation as shown in this (Fig. 2) [1]. While the extensional tectonic regime is shown by microstructure A-symmetrical crenulation, and “domino boudins” (Fig. 3) [1]. The presence of retrograde minerals (high pressure minerals which are replaced by medium and low-pressure minerals indicated if some of Glaucophane undergone retrogradation to Green Schist.

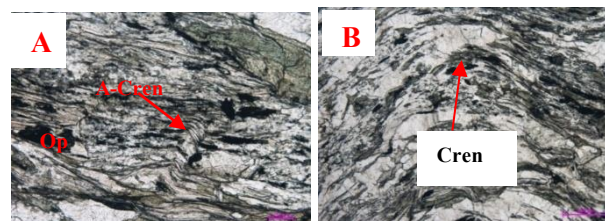


Figure 2. Microphotograph of Mica Schist; Ser: Sericite, Ms: Muscovite, Clz: Clinozoisite, Qtz: Quartz, Op: Opaque minerals, Cren: Crenulation indicating compressional tectonic regimes, and A-cren: Asymmetrical crenulation indicating extensional tectonic regimes [1].

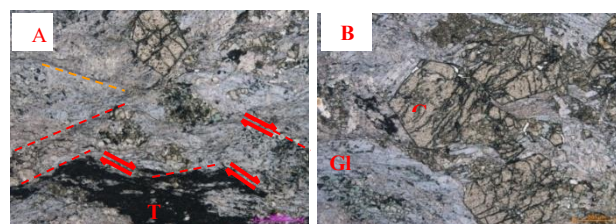


Figure 3. Microphotograph of glaucophane schist; Grt = Garnet; Gln = Glaucophane; Ttn = Titanite; Op = Opaque minerals; C = Fabric/Shear bands cleavage; S = Foliation, Ab = Albite; Ep = Epidote. Domino boudins: indicating of extensional shear zone, refers from (Passchier & Throw, 2005); C-Plane; Garnet porphyroblasts showed footage of pre to inter- tectonic [1].

3.2. Geochemical analysis

Geochemical analysis has been carried out of 12 samples of Glaucophane Schist, and Chlorite Schists collected from Rumbia schist Complex. The results of geochemical analysis include the major elements, trace elements, and rare earth elements. Plotting of the major elements data in the affinity diagram according to [11, 12], shows that the Glaucophane Schist protolith and Chlorite Schist have the affinity of tholeiite series and calc-alkaline series [1]. Plotting multielement diagrams [18], normalized to MORB, shows that the protolith of metamorphic rocks of Rumbia Complex, visible negative anomaly

in the elements of K, Rb and P, and the positive anomalies in Rb, Ba. Furthermore, the results of plotting the Rare Earth Element (REE) are according to [16, 17, 18]. This shows that the protoliths of Glaucophane Schist, and Chlorite Schist from Rumbia Complex as "Oceanic Island Basalt (OIB)" (Fig. 4) [1].

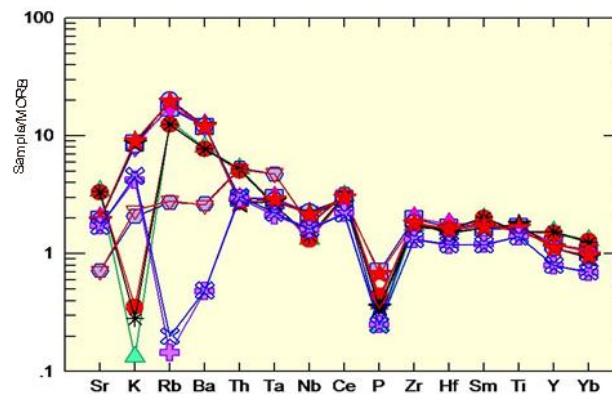


Figure 4. Plotting multi element diagrams [8], normalized to MORB, shows that the protolith of metamorphic rocks of Rumbia Complex, visible negative anomaly in the elements of K, Rb and P, and the positive anomalies in Rb & Ba [1].

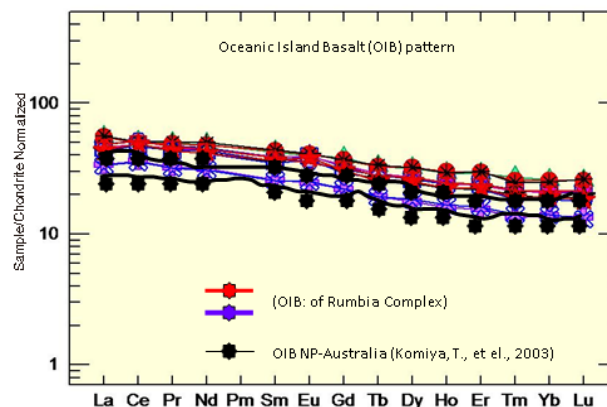


Figure 5. Plotting rare earth element (REE) of glaucophane schist and chlorite schist of Rumbia schist Complex, normalized to Chondrite, after [9], [10]. REE patterns shows that flat pattern, Light-REE (LREE) tight and slightly enriched with a value of 30-60 times against Chondrite; and on the Heavy-REE (HREE) enriched slightly around 10-30 times Chondrite [1].

3.3. Age dating analysis

Radiometric age data obtained from the results of 8 samples of metamorphic rocks using the $^{40}\text{Ar}/^{39}\text{Ar}$ dating method. Consisted of 3 samples of Glaucophane Schist, 2 samples of Chlorite Schist and 3 samples of Mika Schist [1]. Glaucophane Schists have radiometric age spectrum namely: 22.9 ± 0.02 Ma; 20.6 ± 0.1 Ma; 18.7 ± 0.02 Ma; 17.55 ± 0.12 Ma; 10.7 ± 0.33 Ma. Chlorite Schists have radiometric age spectrum: 14.9 ± 0.07 Ma, 14.2 Ma, 12.6 , 12.7 ± 0.03 Ma, 12.6 ± 0.07 Ma, and 6.8 ± 0.64 Ma. While Mika Schist provides an age spectrum: 30.9 ± 1.1 Ma, 26.4 ± 0.23 Ma, 22.5 ± 0.08 Ma, 19.3 ± 0.3 Ma, 18.4 ± 0.03 Ma, 17.2 ± 0.36 Ma, 16.5 ± 0.25 Ma, and 10.75 ± 0.16 Ma [2]. From this age data, then plotting in a synopsis diagram shows that there were 3 periods of major geological events in the Rumbia Complex during the Miocene, namely at 23 Ma, 20 Ma, and 17 Ma [2]; (Fig.6). The major geological events are

known to have a duration of 3 Ma [1]. Therefore, it can be said that during the Miocene, there have been three major geological events in the Southeast Arm of Sulawesi [1].

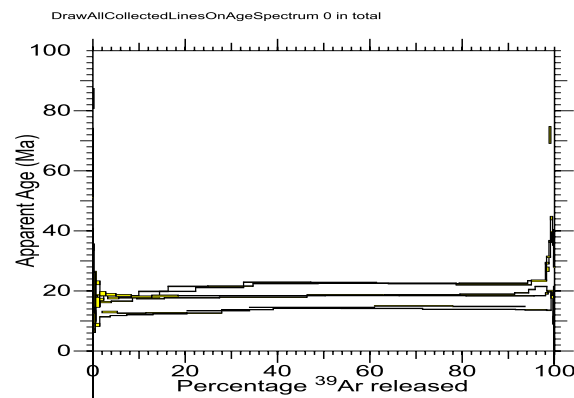


Figure 6. $^{40}\text{Ar}/^{39}\text{Ar}$ Synoptic age spectrum of Rumbia schist Complex [1], [2].

4. Conclusion and discussion

Abundance of silica and high alkaline potassium in Glaucophane and Chlorite schists, is most likely due to hydrothermal effects due to magmatism after collisions with sulfide mineralization in the Southeast Arm of Sulawesi.

Micro-tectonic analysis of metamorphic rocks from Rumbia Complex are known, that at least this area has experienced compressional and extensional tectonic regimes. Compressional tectonic regimes began when subducted between Rumbia and Mekongga Micro Continent around 23 million years ago. In addition, it is very possible that there is another Micro Continent known as the Meluhu Micro Continent which also experienced subduction with Mekongga on the other side, continued to be followed by collisions around 17 Ma ago (Fig.6).

The events of subduction and collisions between the three micro continents caused the amalgamation and formed the Southeast Arm of Sulawesi as we see it today. The amalgamation phase accompanies the emplacement of oceanic crust onto the continental crust which results in such a widespread of ultra-mafic rocks in the Southeast Arm of Sulawesi, as a source of laterite nickel ore. Furthermore, in the Late Miocene in the southern part of the Southeast Arm of Sulawesi, began the movement of the Buton-Tukangbesi Platform towards to the Northwest or Southwest. This subduction event was not followed by collision, because of the occurrence of extensional tectonic regimes with respect to Banda and Deep Weber openings in the Late Miocene (7 Ma) [1].

The presence of gold deposits in the Rumbia Complex, and also in the Mekongga Complex, as a result of magmatism produced by partial melting due to thickening of the crust after the collision between the micro continents of Rumbia, Mekongga and Meluhu.

Synoptic diagrams of $^{40}\text{Ar}/^{39}\text{Ar}$, indicate that in the Rumbia Complex or very possibly in the Southeast Arm of Sulawesi, in the Miocene (23 Ma to 17 Ma) there has been a large geological event with a duration of every 3 Ma.

Metallogeny pathways and sulphide mineralization occur in the Southeast Arm of Sulawesi related to compressional tectonic regimes which produce subduction to collision, accompanied by magmatism. Furthermore, the process of weathering of ultra-mafic rocks, which was interpreted began to continuously since 17 Ma, resulted the deposit of laterite nickel ore in the many location in the Southeast Arm of Sulawesi. Whereas magmatism occurs as a result of the partial melting accompanying the amalgamation that produced of Miocene volcanism (23-7) Ma in the Southeast Arm of Sulawesi. Magmatism and volcanism that also accompanied by sulphide mineralization in host of metamorphic rocks, and very likely in ultra-mafic rocks. Therefore, there is a positive correlation between tectonic evolution in the Miocene, and the pathways of metallogeny in the Southeast Arm of Sulawesi.

Acknowledgement

I thank so much to Gordon Lister for support in this research, Sareh, Davood, and My soulmate Oleg Koudashev from Research School of Earth Sciences, the Australian Nasional University, Canberra, Australia for discussions and cooperation during the fieldwork and in the laboratory analysis, Arif (ITB) for their interactions during my time at ITB. Special thanks to Iref who helped a draft of several figure. I thank also to the Local Government of Bombana Regency for giving permission to take samples in the Rumbia Complex. To Bakri who faithfully accompanied us while doing fieldwork, and lastly, I also say thank you very much to Hasanuddin University for providing opportunities and financial support in this research. The finally to all co-authors who have provided input and correction, I am very grateful.

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