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$^{40}Ar/^{39}Ar$ Geochronology of Rumbia Schist Complex: New Implications For Timing and Hydrothermal Activity in The Southeast Sulawesi Gold Prospect, Indonesia

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ABSTRACT

The Rumbia Mountains, which in this study named Rumbia Complex is an east-west oriented, composed by a high-pressure/low-temperature, and a medium-pressure/low-temperature metamorphic rocks. The complex is identified as mica schist, glauchopane schist, and green schist. Rumbia Complex known as the location of gold deposits prospects discovered by local communities since 2007. The results of research showed that the metamorphic rocks are as hosts. There are two period of gold mineralization that occurs in this area, namely: 1) Associated with tectonic deformation and metamorphic rocks exhumation as a first period, and 2) Gold deposits related to post-tectonic as a result of hydrothermal activity in the Rumbia Complex. Radiometric age dating used $^{40}Ar/^{39}Ar$ geochronology, indicate that the first period of gold mineralization in the Rumbia Complex occurred ≈23 million years ago (MA), and the second period were subsequently overprinting at ≈6.8 million years ago (MA).
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Keywords: *Hydrothermal, Gold, Deposits, $^{40}Ar/^{39}Ar$, Timing, Rumbia, Complex, Southeast, Sulawesi*

1. INTRODUCTION

Rumbia Complex or Rumbia Mountains is located in the southern part of the Southeast Arm of Sulawesi (Figure 1). Those are a folded mountain composed of metamorphic rocks. The highest peak has reaches 1,100 m above sea level. This area is located ±1,800 km east of Jakarta or ±150 km to the south of Kendari City, t e (

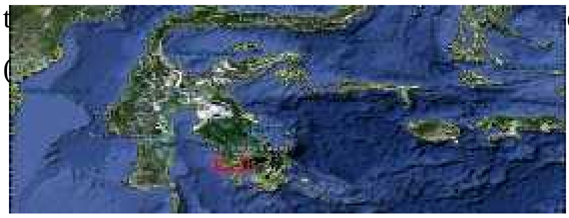

Figure 1 Rumbia Complex (red box); (https// earth.com: Download March 9, 2012).

2. Background

Geological investigation in the Southeast Arm of Sulawesi, especially in the Rumbia Complex, and Mengkongga Complex around Kolaka was i) performed by Wunderlin, Bothe and Hetzel [1]. Petrology Studied and mineralogy has been done by Gisolf [2]. [3, 4] suggest that the metamorphic rocks in the Rumbia Complex, and Mendoke Mountains are epidote amphibolite and glaucophane schist. Unlike in the Central Sulawesi metamorphic rocks are characterized by the presence of jadeite-aegyrine, crrosite, lawsonite and ferrocarpholite; ii) [5] describe the Rumbia Complex as mica-graphite schist and quartzite mica with marble and metabasite intercalation; (iii) [6] identifies the Pompangeo Complex in Central Sulawesi describe of mica schist, chlorite schist, mica-graphite schist, mica-quartz schist, glaucophane schist, amphibolite-ruby schist and gneiss, hornfels, its eclogite is the Late Cretaceous-Paleocene. The same thing illustrated that the Rumbia Complex and Mendoke in Southeast Arm of Sulawesi are Cretaceous-Paleocene. While the Mengkongga Complex, consisting of schist, quartzite and gneiss is the Permo-Carbon; (iv) [7] and [8], assume that the Rumbia Complex as the same metamorphic path with Pompangeo schist Complex in Central Sulawesi, Bantimala accretion Complex in the South Sulawesi and Mengkongga Complex in the Southeast Arm of Sulawesi is the Early Cretaceous in age.

3. GEOLOGY OF RUMBIA COMPLEX

The study area can be distinguished into three geomorphology units, namely: 1) Folded mountain; 2) Hilly, and 3) Plain geomorphology unit. Folded mountains geomorphology includes Rumbia Mountains consist of North Block and South Block, with its highest peak 1,100 m above sea level. This unit occupied ±35% of the study area. North and South Blocks are separated by strike-slip fault zone is relatively east-west trending. Folded mountains geomorphology unit overall occupied by metamorphic rocks. The hilly geomorphology, occupies the west, southwest along the south, approximately ±25% of the study area. The highest point is 60-100 m above sea level. Relief is relatively rough, partly in the form of barren hills with scrub vegetation and grasslands. Common local secondary trees consisting of teak and other wood cultivated plants. This geomorphological unit is partly used as temporary plantation and the settlement by local communities. This area composed by coral reef limestones, conglomerates, and sandstone. Plain geomorphology unit occupies about ±40% of the study area. These units are spread out in the north in the direction of the Langkowala Valley, the west, east and the south that follows the coastline. They are occupied by sandstones, conglomerates, alluvial and beach swampy generally. The northern part of the plain, sedimentary rocks is dominated by conglomerates and sandstones. Both of these lithological units, known as Sulawesi Molasse Sarasin and Sarasin [9], as well refer to it as Langkowala Formation and Alangga Formation. In the central part of the plain, drained by the Langkowala river and Tahiite River. Almost all the locations in the Langkowala Formation and Alangga Formation are a placer gold mining area, a traditional gold mine (small mining).

4. METHODS

Research methodology includes field survey and laboratory analysis: 1) Field survey cover of rocks sampling of alteration and mineralization. 2) Laboratory analysis include thin section analysis by polarized microscope for hydrothermal alteration minerals of 86 six samples, and ore petrography analysis by reflected microscope for ore minerals of 9 samples. While the age analysis and geochronology using $^{40}Ar/^{39}Ar$ age dating by step heating method for 8 samples, as well micro-fossils data integration and interpretation.

5. RESULTS

5.1 HYDROTHERMAL ALTERATION

Hydrothermal minerals analysis by Petrography analysis results of the Glaucophane Schist altered, Chlorite Schist altered and Mica Schist altered collected from Rumbia Complex shown some of these zones have undergone hydrothermal alteration. Alteration percentage ranges from 10% to 80%. Based of alteration minerals assemblage, and based on the classification by Myers [10], the alteration occurred in Rumbia Complex is divided two type, i.e. 1) Propylitic alteration type, and 2) Phylic alteration type.

5.1.1 PROPYLITIC ALTERATION TYPE

Propylitic type developed in almost all lithological units, with the alteration percentage between 10% and 80%. Figure 2 shows a thin section of a propylitic chlorite schist altered with the alteration minerals assemblage: chlorite + epidote + sericite + quartz + carbonate + opaque minerals, as characterized of propylitic alteration type overprinting with phylic alteration type. Glaucophane Schist altered (Figure 3) the degree of alteration apparently up to 75%. The alteration minerals assemblage are chlorite + epidote + quartz ± opaque minerals. This sample shows propylitic type.

5.1.2 PHYLIC ALTERATION TYPE

Phylic alteration type developed in all lithology units of the Rumbia Complex. Developing pervasive alteration in mica schist and chlorite schist. A number of samples are mineralized with sulfide minerals (pyrite, arsenopyrite, cinnabar, antimony, and oxide minerals (hematite and goethite). The following figure is a microphotograph (Phylic alteration type developed in all lithology units of the Rumbia Complex. The alteration in the sample of Glaucophane Albite Schist altered (Figure 4) has altered up to 80% which is accompanied by mineralization, characterized by the presence of opaque minerals. Secondary sericite presence that fills cracks in albite crystals and replaces unknown porphyroblast as pseudomorphs of metamorphic rocks in the Rumbia Complex with phylic alteration.

Microphotograph (Figure 5), appears to be the Glaucophane albite Schist, which has undergone alteration up to 80%, although it is difficult to ascertain, whether previously as Glaucophane albite Schist? This sample has been exposed on the east side of the Rumbia Complex, near the town of Kasipute. This alteration accompanied by sulfide minerals (pyrite and arsenopyrite, galena). Sulfides can be easily been seen with the naked eye as disseminated pyrite minerals in the rocks, associated with quartz veining. The presence of chlorite and sericite minerals indicates that this rock suffered propylitic alteration overprinting by phylic alteration type.

Figure 2 Microphotograph of thin section of chlorite schist altered with minerals assemblage: chlorite, epidote, quartz, carbonate and opaque minerals representing a propylitic overprinting phyllic alteration type.

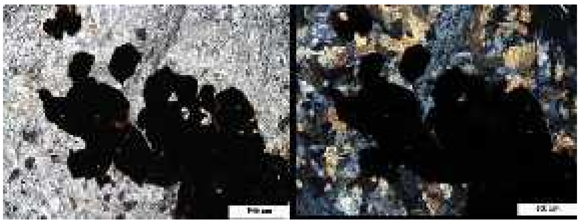

Figure 3 Microphotograph of thin section of Glaucophane Schist altered, minerals assemblage: epidote, chlorite, quartz and opaque minerals represents propylitic alteration.

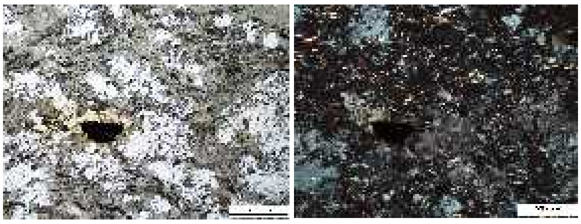

Figure 4 Chlorite Schist, altered up to 80%, minerals assemblage: sericite, chlorite, quartz and opaque minerals, (propylitic alteration overprinting with phyllic alteration type).

Figure 5 Microphotograph of Glaucophane Abite Schist altered, alteration up to 80%. Assemblage minerals: sericite, carbonate aggregate, quartz and opaque minerals (phyllic type).

6. ORE MINERALS

Ore minerals referred to ore petrography was undertaken of nine rocks altered. These samples had significant sulfide-content. Petrography was done on a reflective microscope. The analyses included identification of ore, texture, association and ore paragenesis. Result of analysis, showed that ore minerals associated with sulfide minerals (pyrite, arsenopyrite,

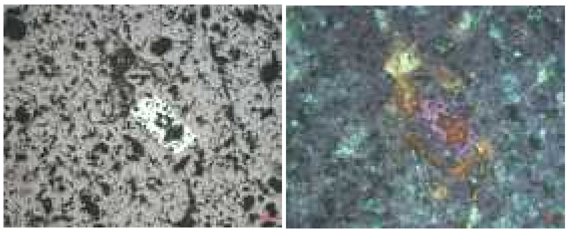

Figure 6 Microphotograph of polish section, showing a prismatic euhedral crystal, possibly hornblende that has been replaced by pyrite (pale yellow).

In (Figure 6), showing antimony minerals associated with pyrite, and partially replaced by iron oxide (hematite) which sporadically occurring within gangue quartz. Antimony interpreted as ore mineral that formed in the initial period of mineralization in the Rumbia Complex.

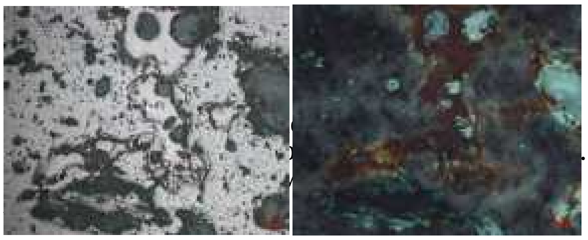

Figure 6 and Figure 7**,** showing that mineralization occurs in two period, namely pre-tectonic period and post-tectonic period. In the early period or pre-tectonic mineralization, hydrothermal solutions filled cracks within the rock and rock foliation and thus were incorporated into the exhumation of the metamorphic rocks by inclusion in the fabric. In contrast, the second period occurs after deformation and it is associated with fluid that caused by alteration in metamorphic rocks. Pyrite appears comes later and spread in the rocks formation, partially filling fissures and cracks in antimony, and anhedral crystal, and indicated as a post-tectonic mineralization. It is very likely, that it presence with regard to the exhumation phase, or extensional regime. While the second phase seems to be presented after deformation, it is most likely associated with hydrothermal solutions that generate alteration in metamorphic rocks.

Cinnabar (Mercury Ore) was found as filling fissures and or replace the existing mineral, overprinting with quartz. The presence of Cinnabar indicates that the carrier of hydrothermal ore minerals associated with magmatism activity. It is understood that Mercury 'HgS' as heavy metals, so it is interpreted that the source of the solution is relatively close to the location of found today. It is interesting to note that Antimony (stibnite ore 'SbS_2') occur earlier before the formation of the cinnabar (Mercury Ore 'HgS'). Antimony is deformed and forming cracks were very intense, and partly replaced by Cinnabar. The ore mineral pyrite cavities filling presented in gangue quartz. The result of hydrothermal ore deposits and a post-tectonic deposit are included in the phase three on the minerals paragenesis in the Complex of Rumbia.

Silver mineral is irregular, cavities filling in a gangue of quartz along with antimony (stibnite). The presence of silver in this sample are as post-tectonic deposits or phase three in ore mineral paragenesis in the Rumbia Complex. The occurrence of silver deposits show that there is hydrothermal deposits associated with magmatism, revealing a silver (white color), as a post-tectonic hydrothermal deposits. Following antimony (stibnite), which comes ahead of silver, can be regarded as deposits or phase two (syn-tectonic). This condition reflects the process of ore deposits which runs continuously from phase two to phase three. Oxide mineralization of ore deposits are related to the final phase of weathering and oxidation. This phase is the period at the end of the mineralization in the Complex which occurs when the host rocks in contact with ground water or surface water or the atmosphere.

7. GOLD DEPOSITS

Gold deposits in the Rumbia Complex, discovered by the local community, in 2007. Geological investigations conducted by [11] concluded that the placer gold deposits in the Langkowala Valley (Bombana) are derived from metamorphic rocks debris in the Rumbia Mountains and Mendoke Mountains. [12] concluded as a primary gold deposits in Bombana (Rumbia Complex) as orogenic gold deposits, and no relation with volcanism. [13, 14] argues that the primary gold deposits in Bombana (Rumbia Complex) associated with hydrothermal alteration in the Early Miocene magmatism. Metamorphic rocks in the Rumbia Complex, and limestones as a host. [14] suggested that the same thing also happens in the metamorphic complex of Mendoke Mountains, and Mekongga to the Northern part of the Southeast Arm of Sulawesi. Early Miocene magmatism occurred as a result of thickening of the crust after the collisional between Rumbia micro-continent and Mekongga, following the amalgamation of Southeast Arm of Sulawesi, Indonesia.

7.1 LOCATION OF GOLD DEPOSITS

Primary gold deposits in the Rumbia Complex, spread at least 4 major locations, i.e. the Northern, Northwest, Central, and Western part of the Rumbia Complex.

Petrographic and mineragraphy analysis and its $^{40}Ar/^{39}Ar$ ages spectra, it is known that the primary gold deposits in the Rumbia Complex are occur in two phases; i) The initial phase relates to the exhumation of *HP* metamorphic rocks. Characterized by presence gold, silver, stibnite, chalcopyrite, galena, and pyrite within the foliation defined by *HP* minerals, where it deposits in fractures, and low stress zones during an intense period of deformation. This mineralization phase classified as syn-tectonic mineralization. In addition, gold has been found in the mica-schist. These locations occur mostly in the northern part and North-West of the Rumbia Complex.

ii) Mineralization is associated with an extensional phase. In this phase, the ore minerals pseudomorph mafic minerals, infill cavities and fractures. In general, gold mineralized bearing quartz veins occur during deformation or syn-tectonic to post-tectonics. Some of ore deposits (e.g. electrum) is found as an inclusions, or are disseminated in the rocks, frequently in a gangue quartz. In the mica schist gold deposited after or late in the formation of the white-mica defined foliation, in low strain zones, fractures and cracks.

6. ^{40}AR/^{39}AR GEOCHRONOLOGY AND TIMING OF GOLD MINERALIZATION

$^{40}Ar/^{39}Ar$ dating has been done of rock with mineralization from the key mineralization locations. An array of ages have been determined showing that mineralization has occurred at different times. Results of $^{40}Ar/^{39}Ar$ dating of the *HP* metamorphic foliation is from ≈23 Ma to ≈6.8 Ma suggesting that mineralization may have occurred in this zone during that time. Because the gold mineralization occurred during the foliation formation it is suggested that the Phase 1 was deposited at ≈23 Ma. This phase of gold mineralization has been found in situ in the *HP* metamorphic rocks as well as Placer gold after the erosion.

8. ORE PARAGENESIS

Ore mineral texture analysis results through a polish section, and integrated analysis of the hydrothermal alteration minerals, known that the ore mineral deposits in the study area was divided into four (4) phase, i.e:

Phase 1: At this phase of ore deposits formed before the tectonic deformation or commonly referred to as pre-tectonic deposits. Ore minerals were formed are antimony, galena, chalcopyrite, cinnabar, magnetite and pyrite. **Phase 2: W**hich formed the ore deposits associated with hydrothermal flow through rock fractures associated with metamorphic exhumation and upthrusting. Furthermore ore deposits or filling in the fractures and in the metamorphic rocks foliation. Ore deposits such as these occur as syn-tectonic deposits. Minerals that form the antimony, galena, pyrite, chalcopyrite, cinnabar, silver, gold, and magnetite. **Phase 3:** Mineral deposits formed after tectonic deformation, and in this study is referred to as post-tectonic deposits. Minerals that form the chalcopyrite, pyrite, cinnabar, silver and gold. At this phase with respect to the ore deposits hydrothermal alteration. **Phase 4:** The ore deposits were formed at the end of the period of mineralization in the Rumbia Complex. Tabel 1, showing ore minerals paragenesis in the Rumbia Complex.

Table 1 Ore minerals paragenesis

Ore	Phase-1	Phase-2	Phase-3	Phase-4
Antimony	—	—		
Galena	—	—		
Chalcopyrite	—	—	—	
Arsenopyrite		—	—	
Pyrite	—	—	—	—
Silver		—	—	
Cinnabar		—	—	
Gold/Electrum		—	—	
Magnetite	—	—		
Fe-Oxide				—

Source: Musri (2015)

9. Discussion and Conclusion

Rumbia metamorphic rock Complex have been hydrothermal altered, and based on the mineral assemblage are classified as phylic type overprinting propylitic alteration type. The minerals assemblage of phylic alteration type are: Ser+Cal+Qtz±Oq; while prophylitic alteration have the minerals assemblage are: (1) Act+Cal+Qzt±Oq;(2)Ep+Chl+Cal±Qzt±Oq.

In general, based on $^{40}Ar/^{39}Ar$ age spectrum indicates that the Glaucophane Schist provide age spectrum between 23 Ma - 11 Ma. Mica schist giving age spectrum 31 - 11 Ma. Furthermore, chlorite schists giving ages spectrum at 15 Ma - 7 Ma. Referring to the $^{40}Ar/^{39}Ar$ age spectrum against Glaucophane Schist, Mica Schist, and Chlorite schist, integrated with petrographic data, mineragraphy and regional tectonic data, it can be conclude that the tectonic events that occur in Rumbia Complex, is as follow:

Phase 1: There are two micro continent, moving closer to each other. Before each of which has oceanic crust. One of the micro-continent is Proto-Rumbia, whose front section is formed Oceanic Island Basalt (OIB) prior to subduction occurs. Subduction occurs between the Proto-Rumbia and Proto-Mekongga accompanying the oceanic crust. These events resulted of metamorphism of OIB on 23 Ma - 17 Ma, accompanied emplacement of oceanic crust. In this phase Glaucophane Schists formed at 23 Ma, with protolith OIB).

Phase 2: Continued subduction events that followed by collisions, which is interpreted occurred on 17 years ago, marking the amalgamation phase of Proto Mekongga, Proto-Rumbia, and Proto-Meluhu, which is now known as the Southeast Arm of Sulawesi. This phase is interpreted as a first period of gold mineralization that occurs in the Rumbia Complex, or at least the first phase of mineralization in the Rumbia Complex occurs between 23-11 million years.

Phase 3: Collision peak interpreted occurred in 17 million years ago, the extensional phase followed interpreted taking place since 15 million years and lasted up to 7 million years ago. End of this extensional events would be marked by the cessation of the growth of the reef, and is the beginning of turning the compressional tectonic regime that followed by magmatism and produce dacite intrusion in the Mekongga Complex. To believe, the compressional regime event continues until Pleistocene, characterized by the growth of reefs in the Southeast Arm of Sulawesi in the Holocene. In this tectonic regime latter (after 7 million years), are thought to result and produces hydrothermal alteration and gold mineralization in the Rumbia Complex (second period).

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