Hydrothermal alteration and timing of gold mineralisation in the Rumbia Complex, Southeast Arm of Sulawesi, Indonesia

Musri Mawaleda¹, Emmy Suparka², Chalid Idham Abdullah², Nurcahyo Indro Basuki², Marnie Forster³, Jamal¹, Kaharuddin¹

¹Department of Geology, Hasanuddin University, Makassar, Indonesia
²Department of Geology, Institute of Technology Bandung, Indonesia
³Research School of Earth Sciences, Australian National University, Canberra, Australia

Corresponding author’s: musri.mawaleda@unhas.ac.id

Abstract. The Rumbia Mountains, which in this study named Rumbia schist Complex is an east-west oriented, composed by a high-pressure/low-temperature, and a medium-pressure/low-temperature metamorphic rocks. 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 phase of gold mineralization that occurs in this area, namely: 1) Associated with tectonic deformation and metamorphic rocks exhumation, and 2) gold-related hydrothermal deposits. Radiometric age dating used ⁴⁰Ar/³⁹Ar geochronology, indicate that the first of gold mineralisation in the Rumbia Complex occurred ~23 million years ago, and the second gold mineralisation were subsequently overprinting at 7 million years ago.

Keywords: Hydrothermal, Gold, Deposits, ⁴⁰Ar/³⁹Ar, 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 seal level. This area is located ±1,800 km east of Jakarta or ±150 km to the south of Kendari City, the capital of Southeast Sulawesi Province (Figure 1).

2. Background
Geological investigation in the Southeast Arm of Sulawesi, especially in the Rumbia Complex, and Mengkongga Complex around Kolaka was first performed by; (i) Wunderlin (1913); Bothe and Hetzel (1932) in Bemmlen (1949). Petrology Studied and mineralogy has been done by Gisolf, 1924 in Bemmlen (1949); De Roever (1947, 1950, 1956), suggests 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, errosite, lawsonite and ferrocarpholite; (ii) Helmers et al. (1989) describe the Rumbia Complex as mica-graphite schist and quartzite mica with marble and metabasite intercalation; (iii) Simandjuntak et al. (1994) identifies the Pompangeo Complex in Central Sulawesi describe of mica schist, chlorite schist,
mica-graphite schist, mica-quartz schist, glaucophane schist, amphibolite-ruby schist, gneiss, hornfels, and 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) Parkinson (1998) and Kadarusman et al. (2004), assume that the Rumbia Complex as the same metamorphic path with Pompango Complex in Central Sulawesi, Bantimala accretion Complex in the South Sulawesi and Mekongga Complex in the Southeast Arm of Sulawesi is the Early Cretaceous in age.

These last few years, discovered placer gold deposits in the Rumbia Complex, allegedly derived from schist and metabasite debris in the Rumbia Complex, and Mendoke Mountains (Surono and Tang, 2009). Idrus et al, (2010) proposed that the placer gold deposits in the Langkowala Valley (Rumbia Complex) as orogenic gold deposits are associated with the formation of metamorphic rocks that are completely unrelated to the volcanic activity.

**Figure 1.** Location of study area 'red box' is it the Rumbia Complex (https://earth.com; Download January 9, 2016).

**Figure 2.** Geological map of Rumbia Complex, Southeast Arm of Sulawesi, Indonesia (Musri, 2015).
3. Geology of Rumbia Complex

Based on the relief, the study area can be distinguished into three geomorphology units, namely: 1) Folded mountain geomorphology unit; 2) Hilly geomorphology; and 3) Plain geomorphology unit. Folded mountains geomorphology unit 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 mountain geomorphology unit, the overall occupied by metamorphic rocks.

The hilly geomorphology unit, occupies the west, southwest along the south of the Rumbia Mountains, approximately ±25% of the study area. The highest point is 60-100 meters above sealevel. Relief relatively coarse, 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 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 and the east and south that follows the coastline.

Plain geomorphology unit, generally occupied by sandstones, conglomerates, alluvial and beach swampy. The northern part of the plain, sedimentary rocks are dominated by conglomerates and sandstones. Both of these lithological units, known as Sulawesi Molasse (Sarasin and Sarasin 1901 in Bemmelen 1949). While Kartadiputra (1983) refer to it as Langkowala Formation and Alangga Formation. In the central part of the plain geomorphology unit, drained by the Langkowala river and Tahiite River.

Almost all locations in the Langkowala Formation and Alangga Formation is a placer gold mining area, as a traditional gold mine, organized by local communities.

4. Research Methodology

Research methodology includes field survey and laboratory analysis: 1) field survey cover of rocks sampling of alteration and mineralization. 2) laboratory analysis include petrographic analysis by thin section for hydrothermal alteration minerals, and ore petrography analysis by polish section for ore minerals. While the age analysis using micro fossil data and radiometric age dating of $^{40}\text{Ar}/^{39}\text{Ar}$.

5. Result and Discussion

5.1. Hydrothermal Alteration of Rumbia Complex

Hydrothermal minerals analysis by petrography analysis results of the Glaucophane Schist altered, Chlorite Schist altered and Mica Schist altered. The ranges of alteration from 10% to 75%, and divided into two type, i.e. propylitic alteration and phylic alteration type.

5.1.1 Propylitic alteration type

Propylitic type developed in almost all lithological units, with the alteration percentage between 10% until 75%. Figure 3 shows a thin section of a propylitic chlorite schist altered, and alteration in Figure 4, shows the percentage of alteration up to 50-75%. Alteration minerals assemblages are chlorite, epidote, sericite, quartz and opaque minerals. This sample shows propylitic alteration overprinting with phylic alteration type.

5.1.2 Phylic alteration type

Phylic alteration type developed in all lithological 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 and antimony), and oxide minerals (hematite and goethite). The following figure is a microphotograph (Figure 5) of metamorphic rocks of the Rumbia Complex with phylic alteration.
Figure 3 Microphotograph of thin section of Chlorite Schist Altered with alteration minerals assemblage are chlorite, epidote, quartz, sericite, carbonate and opaque minerals representing a propylitic overprinting phyllic alteration type.

Figure 4 Microphotograph of thin section of Glaucophane Schist Altered, where alteration is up to 75%. Assemblage of alteration minerals, i.e. epidote, chlorite, quartz and opaque minerals.

Figure 5. Microphotograph of thin section of chlorite schist (RS-38-11), alteration up to 60%. (propylitic overprinting with phyllic alteration).
The alteration in the Sample of Glaucophane Albite Schist altered (Figure 6) has alteration up to 75% which is accompanied by mineralization, this is also characterized by the presence of opaque minerals. Secondary sericite is also present that fills cracks in albite crystals and replaces unknown porphyroblast as pseudomorphs.

![Figure 6. Microphotograph of thin section of glaucophane albite schist altered, with alteration up to 75% (phylic type).](image)

The microphotograph of alteration in Figure 7 is suggested to have been a glaucophane albite schist, although this is difficult to be sure. This sample has only been found only exposed on the East Side of Rumbia Complex, near the Kasipute City. This alteration at this location is accompanied by sulfide minerals (pyrite and arsenopyrite, and galena). Sulfides can be easily been seen with the naked eye as disseminated pyrite minerals in the rocks, fissure veins and filling fractures associated with quartz veining. The presence of chlorite and sericite minerals, indicating that this rock which suffered propylitic alteration overprinting by phylic alteration type.

![Figure 7 Microphotograph of thin section of altered rock (RS-30C-11), it is suggested to be an altered glaucophane albite schist. The alteration percentage is up to 75%, with assemblage minerals: sericite, chlorite, calcite, quartz, opaque minerals.](image)

5.2. Ore petrography
Ore petrography was undertaken of nine rocks altered sample of Rumbia schist Complex. These samples had significant ore sulfide-content. The analyses included identification of ore, texture, association and ore paragenesis. Result showed that ore minerals are associated with sulfide minerals (pyrite, arsenopyrite, antimony, galena and cinnabar). There is also an associated with oxide minerals (hematite, and goethite). See Table 1 Ore mineral paragenesis (growth phase).

In this this sample (Figure 8), showing antimony associated with pyrite, and partially replaced by iron oxide (hematite) which sporadically occurring within gangue of quartz. Antimony interpreted as ore mineral that formed in the initial period of mineralization in the Rumbia Complex.

Figure 8 Microphotograph of polish section, showing a prismatic euhedral crystal, possibly hornblende that has been replaced by pyrite (pale yellow).

Figure 9 Microphotograph (RS-23A-11) showing antimony (fibrous), irregular, gray color. Iron oxide which is brown in cross polar (XPL), is filling the fractures

Figure 8 and Figure 9 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 this deformation and it is associated with fluid that caused by alteration in metamorphic rocks (look Figure
In Figure 10, appears pyrite comes later, spread in the rocks formation, partially filling fissures and cracks in antimony, and anhedral crystal, and indicated as a post-tectonic mineralization. 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.

![Image](image1.png)

**Figure 10.** Microphotograph of polish section: showing pyrite, white color (ppl), to be disseminated within the rock. The pyrite is seen as anhedral grains and is classified as post-deformation mineralization. Antimony (gray color) was dominant in the rock, and is fibrous, anhedral and deformed. This suggests mineralization as a pre-tectonic or early syn-tectonic mineralization

In Figure 11, appears Cinnabar (Mercury Ore), filling fissures and or replace the existing mineral, overprinting with quartz. However the presence of Cinnabar, indicating that the carrier of hydrothermal ore minerals associated with magmatism activity. In this case, understood that Mercury 'HgS' as heavy metals, so it is interpreted that the source of the solution is relatively close to the location found today. Interesting to note, that in Figure 11, it seems antimony (stibnite ore 'SbS$_2$'),

![Image](image2.png)

**Figure 11** Microphotograph of polish section (RS-23B2-11) shows Mercury ore (Cinnabar 'red color') overprinting with quartz. Mercury Ore (Cinnabar) replaces existing minerals, or filling cavities.
visible presence early, before the formation of the cinnabar (Mercury Ore 'HgS'). Antimony is deformed, forming cracks were very intense, and partly replaced by Cinnabar.

In Figure 12, shows the ore mineral pyrite cavities filling presented in gangue quartz. Is the result of hydrothermal ore deposits and as a post-tectonic deposit are included in the phase three on the minerals paragenesis in the Rumbia Complex.

![Figure 12](image1.png)

**Figure 12.** Microphotograph of polish section (RS-07-12); Showed, pyrite present to filled the cavity (as a post-tectonic deposits) in a gangue of quartz.

![Figure 13](image2.png)

**Figure 13.** Microphotograph, sample code: RS-23B1; Silver (white color ) filling the cavity of a stibnite (antimony). At the edge of the crystals appears to corrosion as a result of weathering.

Figure 13, shown the silver minerals, which 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. Figure 14, showing electrum (yellowish white), irregular, as inclusions in gangue of quartz, disseminated sporadically in the rock. Electrum presence in the rock samples it is a hydrothermal deposits are post-tectonic (phase 3). While in Figure 15, shows a oxide mineralization of ore deposits related to the final phase of weathering and oxidation. This phase is the period at the end of the mineralization in the Rumbia Complex. Occurs when the host rocks in contact with ground water or surface water or the atmosphere.
5.3. Gold deposits

Gold deposits in Rumbia Complex, discovered by the local community, in 2007. Thereafter geological investigations conducted by Surono and Tang (2009) concluded that the placer gold deposits in the Langkowala Valley (Bombana), derived from metamorphic rocks debris in the Rumbia Mountains and Mendoke Mountains (metamorphic complex). Furthermore, Idrus (2010) concluded as a primary gold deposits in Bombana (Rumbia Complex) as orogenic gold deposits, and not relation with volcanism. While Musri (2011, and 2015), argues that the primary gold deposits in Bombana (Rumbia Complex), associated with hydrothermal alteration in the Early Miocene magmatism. So the metamorphic rocks in the Rumbia Complex, and limestones as a host. Musri (2015) also of the view 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.
5.4. 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 (See: Figure 16).

![Figure 16](image)

**Figure 16** Map location of gold mineralization in the Rumbia Complex. Phase 2 is the first timing of gold mineralization, and phase 3 is the second timing of gold mineralization (look: Table 1, the phase of ore paragenesis in the Rumbia Complex).

Based on the petrographic analysis, ore petrology and $^{40}\text{Ar}^{39}\text{Ar}$ ages spectrum, 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. Mineralization is characterized by presence of 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 (Figure 17). This mineralization phase is 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 (Figure 16). 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 (Figure 18); (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 syntectonic to post-tectonics (Figure 19). Some of ore deposits (e.g. electrum) is found as an inclusion, or are disseminated in the rocks, frequently in a gangue of quartz (Figure 20).
Figure 17 Fractures filled by gold within glaucophane schist fragment (molasses fragment of Amitopa River, North Poleang, Bombana).

Figure 18. Fissure veins and or foliation filled by gold in the mica schist fragment (placer deposits) from Amitopa River, North Poleang, and Bombana. The first of gold mineralization period.

Figure 19 Gold deposits bearing quartz (placer gold deposits). The second primary gold deposits. Quartz grain comes from metamorphic rocks debris (mica schist, gaucopehane schist, and chlorite schist) of Rumbia Mountains.

Figure 20 Electrum (fine grains) disseminated in the gangue of quartz, location from Rau-Rau (close to the host spring. The second stage of gold mineralization in the Rumbia Complex.

5.5. $^{40}$Ar/$^{39}$Ar Age dating and timing of gold mineralization in the Rumbia Complex

$^{40}$Ar/$^{39}$Ar dating has been done on the metamorphic rock with gold content 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 ~11 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.

5.6. Ore paragenesis in the Rumbia Complex

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:** In phase 2, which 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:** In phase three, 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:** Phase 4 is the ore deposits were formed at the end of the period of mineralization in the Rumbia Complex. This event with respect to oxidation as a result of the formation is influenced, groundwater, atmosphere, and or weathering. Also referred to as oxide ore deposits. Table 1, showing ore minerals paragenesis in the Rumbia Complex.

| Ore minerals   | Phase 1 | Phase 2 | Phase 3 | Phase 4 |
|----------------|---------|---------|---------|---------|
| Antimony       |         |         |         |         |
| Galena         |         |         |         |         |
| Chalcopyrite   |         |         |         |         |
| Arsenopyrite   |         |         |         |         |
| Pyrite         |         |         |         |         |
| Silver         |         |         |         |         |
| Cinnabar       |         |         |         |         |
| Electrum/gold  |         |         |         |         |
| Magnetite      |         |         |         |         |
| Fe-Oxide       |         |         |         |         |

**Source:** Musri (2015)

5.7. Geology model of gold deposits in the Rumbia Complex

The geological model of gold deposits in the Rumbia Complex is based on ore petrography, ore minerals paragenesis, the evolution of metamorphism and tectonic evolution in space and time. Approach model to integrate the age data of metamorphic rocks, tectonic evolution, and geological formation of gold deposits in the Rumbia Complex. As shown in Figure 21 and Figure 22, are the
alternative scenarios of the geological model of gold deposits in the Rumbia Complex. The first alternative scenario (Figure 21), on the understanding that Rumbia Complex as a micro-continent that is different from other continental in the Southeast Arm of Sulawesi (Musri, 2015). In this context, the Proto-Rumbia Microcontinent suffered subduction with Proto-Mekongga Microcontinent in the North part of Southeast, which ended with a collision and caused by emplacement of ultramafic rocks that is currently known as Mendoke Mountains (Musri, 2015). This scenario, the case relates to the end of metamorphism. Hot solution can be derived from Uppermost Mantle, which carries out ore minerals, mixed with meteoric water, and precipitation in the rock mass. In this case, the fracture, and foliation, could act as a canal way. Based on the radiometric age data, at least occurred after 23Ma. As the initial phase of glaucophane schist formation. Allegedly occurred during the 23-11 Ma.

Figure 21 The first scenario, formation of primary gold deposits in the Rumbia Complex, which is interpreted that the hydrothermal solution moves up began in Figure 5.6 (A). In this model the Proto Rumbia Complex as micro-continent, before experiencing subduction that began 31 Ma, with Proto-Mekongga Microcontinent, as well as collision at 17 Ma.

The second alternative scenario it is possible the contribution of new subduction by others micro-continent in the South or Southeast of the Rumbia Complex (Figure 22). Very likely a micro-continent Buton as hypothesized by Ali et al., (1996). In this scenario, gold mineralization occurs in conjunction with extensional phase. Based on data from radiometric ages of the metamorphic rocks in the Rumbia Complex, the events of this mineralization occurred on 15 Ma to 7 Ma. Gold mineralization of this phase, interpreted as a second phase of gold mineralization in the Rumbia Complex, which can be
observed in the textural of ore minerals as electrum, anhedral, and disseminated in the rocks, and cavities filling.

Figure 22 The second scenario of gold deposits in the Rumbia Complex. In this model, the contribution of the subduction of Buton-Tukangbesi platform result of partial melting and intruding asthenospheric wedge (adapted model from Lister and Forster (2009).

6. Conclusion
Rumbia metamorphic rock Complex have been hydrothermal altered, and based on the mineral assemblage are classified as phyllic type overprinting propylitic hydrothermal alteration type. Phyllic alteration type; the minerals assemblage are: Ser+Cal+Qtz±Oq; while propylitic alteration type have the minerals assemblage are: (1) Act+Cal+Qtz±Oq; (2) Ep+Chl+Cal±Qtz±Oq. In general, based on $^{40}\text{Ar}/^{39}\text{Ar}$ age spectrum indicates that the Glaucophane Schist provide age spectrum between 23 Ma - 11 Ma. Mica schist give age spectrum 31 - 11 Ma. Furthermore, chlorite schists giving ages pectrum at 15 Ma - 7 Ma. Referring to the age spectrum $^{40}\text{Ar}/^{39}\text{Ar}$ 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 Oceanic Island Basalt (OIB) on 31 Ma-17 Ma, accompanied by emplacement of the oceanic crust. In this phase Glaucophane Schists formed at 23Ma, with protolith of Oceanic Island Basalt (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. In this phase, interpreted as a first phase 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 Ma ago.
Phase 3: Collision peak interpreted occurred in 17 million years ago, the extensional phase followed interpreted taking place since 15 million years ago 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 Ophiolite complex (Mendoke Mountain).

7. Acknowledgments
Many thanks to Gordon Lister, Oleq Koudashev, Davood, Jessica and Sareh, for discussion and interaction during in the RSES, The Australian National University, Canberra, Australia. My colleagues at Hasanuddin University, Makassar and ITB, Bandung, Indonesia for discussion and interaction during the research and preparing this paper.

8. References
[1] De Roever, W P., 1950: Preliminary notes on glaucophane-bearing and other crystalline schists from Southeast Celebes and on the origin of glaucophane-bearing rocks, Proc.K.ned.Akad. Wet.LIII-9 2-12.
[2] De Roever, W P., 1956: Some additional data on the crystalline schists of the Rumbia and Mendoke mountains, Southeast Celebes, Verh. K. Ned. Geol.-mijnb. Genoot, XVI:385-393.
[3] Forster, M.A. And Lister, G S., 2004: The interpretation of $^{40}\text{Ar}/^{39}\text{Ar}$ apparent age spectra produced by mixing: application of the method of asymptotes and limits. Journal of Structural Geology.
[4] Idrus A, Warmada I W, Nur I, Sufriadin, Imai A, Widiasaputra S, Marlia S I, Fadlin and Kamarullah, 2010: Metamorphic rock-hosted orogenic gold deposit as a source of Langkowala palcer gold, Bombana, Souteast Sulawesi, Indonesia Proceedings PIT IAGI Lombok 2010 The $^{39}$th IAGI Annual Convention and Exhibition, p7.
[5] Lister, G S., and Forster, M., 2009: Tectonic mode switches and the nature of orogenesis, Lithos.
[6] Musri, Suparka E, Abdullah C I, 2011: Preliminary study of sulfide mineralization in limestone hosted, Bombana Area, Southeast Sulawesi, Indonesia.
[7] Musri, 2015: Metamorphic Rocks Evolution of Rumbia Complex, Southeast Arm of Sulawesi and its relation to gold deposit, Dissertation of ITB (unpublished).
[8] Parkinson C D., 1998: An Outline of the petrology, structure and age of the Pompangeo Schist Complex of Central Sulawesi, Indonesia, The Island Arc 7, 231-245.
[9] Simandjuntak T O, Surono dan Sukido 1993: Peta geologi Lembar Kolaka, Sulawesi, sekala 1 : 250.000, Pusat Penelitian dan Pengembangan Geologi, Departemen Pertambangan dan Energi RI.
[10] Surono, 1994: Stratigraphy of the Southeast Sulawesi continental terrane, Eastern Indonesia, Journal of Geology and Mineral Resources, No 31, IV, p12.
[11] Surono, 1998: Geology and origin of the Southeast Sulawesi continental terrane, Indonesia, Media Teknik XX(3), 33-42.
[12] Surono, Tang H A 2009 Batuan pembawa emas primer dari endapan emas sekunder di Kabupaten Bombana, Sulawesi Tenggara, berdasarkan interpretasi indera jauh, Prosidings PIT IAGI Semarang, 2009, Indonesia 11h.
[13] Map of Sulawesi. GoogleEarth. https//earth.com: Download on Januari 9, 2012.