GEOLOGY AND ORE CHARACTERISTICS OF LOW SULFIDATION EPITHERMAL GOLD MINERALIZATION AT TAMBANG SAWAH, LEBONG, BENGKULU PROVINCE

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Abstract —Tambang Sawah Area, Lebong Regency, Bengkulu Province, is geologically located in the Barisan mountains and Sumatra fault zone. The prospect of Tambang Sawah area lies in the physiography of the central Sumatran mountain's ranges composed by the igneous rocks of the Sunda – Banda magmatic arc. This study is aimed to understand the deposit geology and ore characteristics of the gold deposit at the study area. Quartz vein mineralization of Tambang Sawah occurred in granite rock intruded into andesitic breccia rocks, with the geological structure of mineralization control in the form of joint, breccia, dike, and fault, namely the Ketahun fault that forms extentional fracture zones which were filled by hydrothermal fluid in form of quartz veins. Hydrothermal alterations that appear at the study site are typical types of alterations found in epithermal gold deposits, namely, argillic, silicified and propylitic. Sulfide minerals markers of low sulfidation epithermal type gold deposits found, namely, pyrite, calcopyrite, covelite, sphalerite and galena with colloform vein texture, cockade-crustiform, moss, and brecciated texture. Gold is interpreted to be derived from the deposition of sulfide minerals and the deposition of quartz veins, the level of gold in rocks and veins varies greatly with an average 4,8 ppm. Based on the results of ore geochemical analysis of positively correlated gold with elements Ag, Cu, Pb and Zn.

Keywords: Mineralization, low sulfidation epithermal gold, Tambang Sawah, Lebong, Bengkulu.

I. INTRODUCTION

Indonesia is a country that is blessed with abundant natural resources, especially in terms of geological resources. The island of Sumatra, which is located a subduction zone between two major plates in the world, namely the Indo-Australian plate and the Eurasian plate, is a zone where natural resources are found, one of which is metallic minerals. Convergent plate boundaries, especially the subduction zone, will produce types of mineral deposits such as porphyry Cu, Mo, Au, epithermal Au-Ag, Cu-Zn and orogenic Au [3]. The Tambang Sawah area of Lebong Regency, Bengkulu Province, is geologically located in the Barisan Mountains and the Sumatran fault zone, which is part of the subduction zone. The existence of this subduction process allows this area to produce low sulfidation epithermal gold (Au) mineralization deposits. Gold veins in low sulfidation epithermal deposits are abundant in the western Sunda-Banda arc [5]. The Tambang Sawah, Lebong is one of the areas on the island of Sumatra which is passed by the Sunda-Banda magmatic arc zone. Studies on the geology of Sumatra and mineral deposits in Sumatra have been carried out [23] and reviewed [4], regarding the mineral potential in the form of gold-silver (Au-Ag) deposits found in the Lebong Tandai and Lebong Donok areas, as well as research [22] in the North Lebong area, showing that the influence of hydrothermal solutions on rocks such as andesite and tuff, dacite, breccia and granodiorite, is a fairly good geological environment for mineralization from low-temperature hydrothermal solutions (*epithermal mineralization system*). In this area, no detailed research has been carried out regarding the geological characteristics and metal mineralization. In this regard, it is necessary to conduct detailed research related to geological characteristics, alteration, and mineralization in the Sawah Mine and surrounding areas to support data on the discovery of new primary gold deposits which will later be used as a reference in exploration and exploitation of low-sulfidation epithermal primary gold in Lebong

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Regency. which is on the line of the Barisan mountains, Sumatra Island. This study aims to determine the geological conditions that control the mineralization and characteristics of epithermal gold deposits through field mapping, petrographic analysis of the rocks that make up the study site, ore microscopy, and geochemical characteristics of ore minerals that can be used as a reference for more detailed exploration.

A. Regional Geology

The Lebong Regency area is in the central part of the southern part of the island of Sumatra. The Tambang Sawah, located to the north of Lebong, is in the Central Sumatran Barisan zone which extends in the NW - SE (Northwest-Southeast) direction [23]. Along the Barisan zone, there is a median depression zone which is characteristic of the Barisan zone which is called the Semangka (rift) zone [23]. This area is formed in the form of a narrow valley that extends and volcanic-tectonic deposits. Tambang Sawah which is the path of the Ketahun Fault which is a segment of the Sumatran Fault system is located between the graben valley or the Ketahun basin. The North Lebong area is included in the row zone which is to the east of the Bengkulu Basin. The stratigraphy of this area is composed of rocks that vary from Pre-Tertiary to Quaternary age. The stratigraphic order around Bengkulu and the row zone around Bengkulu by age from old to young have been mapped [11] [21] (**Fig. 1**). Pre-Tertiary age rocks found in this area are granite (Kgd) of late cretaceous found scattered locally (locally) in the western area of the Ketahun fault line which is a segment of the Sumatran Fault. Granite is found in the west of Tambang Sawah, in the area around Talangbaru, Talang Bandaragung, Bukit Sanggul, Bukit Tabangtengah and around Mount Gumai [10]. At the tertiary age, volcanic rocks were deposited which compose most of the Barisan zone [10]. The Hulusimpang (Tomh) Formation is exposed in almost the entire Barisan zone, extending from southeast to northwest. The Hulusimpang Formation is a Tertiary volcanic product. The Hulusimpang Formation consists of lava, volcanic breccia, and altered tuff, ranging from andesite to basalt. The geological structure that developed in the Lebong area shows the main structure, namely the Ketahun Fault which has a northwest-southeast (NW-SE) [11] [21], which is part of the Sumatran Fault segment [17]. The dominant lineament pattern can be seen from the results of mapping [11] [21], showing a northwest-southeast (NW-SE) pattern in the direction of the main fault (Ketahun Fault). In addition, the northeast-southwest (NE-SW) and north-northeast-southeast (NNE-SSW) lineament patterns are also seen. **(Fig. 1).**

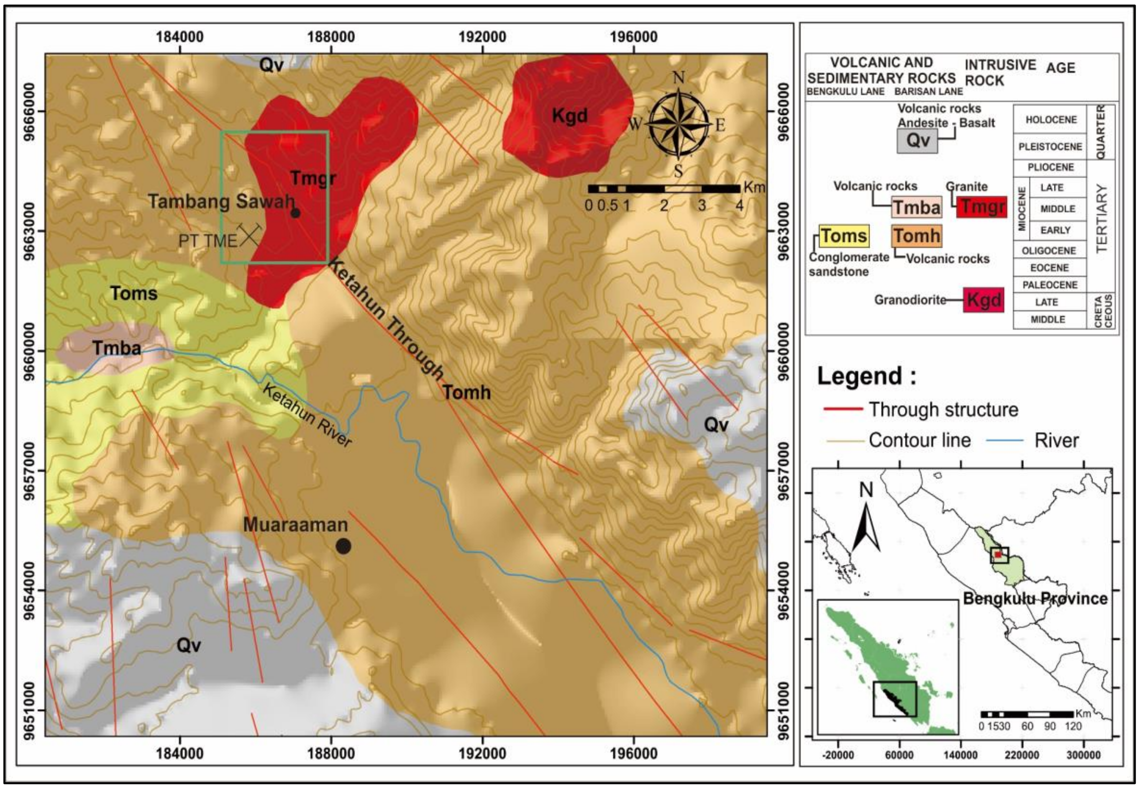

Figure 1. Regional Geological Map of the study area with a modification of the Bengkulu Regional Geological Map Sheet 1:250,000 Scale (Gafoer et al, 1992). The green box is the research area.

II. RESEARCH METHODS

The research methodology is divided into two, namely field observation and laboratory. Field observations include geological mapping, vein, and rock sampling. Geological mapping is carried out to identify lithology, geological structures, alterations, and veins equipped with data on thickness, direction, slope, sketching of outcrops, and taking photos. In addition, rock samples were taken using the grab sampling method including samples of fresh rock, altered rock and veins. Laboratory observations include petrographic observations of 16 samples, to determine the minerals that make up the rock in the study area, ore microscopy observations of 14 samples of rocks and veins to determine the variation of sulfide minerals present. Petrographic analysis and ore microscopy was carried out at the Minerals Laboratory, Department of Geological Engineering, Faculty of Engineering, University of Gadjah Mada, X-Ray Diffraction (XRD) analysis of 11 samples of rock powder and veins that had been made previously, to find out all the mineral content contained in the altered rock in detail and carried out at the Petroleum Engineering Laboratory of UPN "Veteran" Yogyakarta, and 10 samples of Fire Assay – Atomic Absorbtion Spectometry (FA-AAS) ore geochemical analysis, to determine metal content in rocks and veins, were carried out at the ALS Geochemistry Laboratory in Vancouver, Canada.

III. RESULTS AND DISCUSSION

A. Deposit Geology

1. Lithology

At deposit scale, the study area is occupied by two main lithological units mainly andesitic breccia and granite. Andesitic breccia is thought to have formed due to contact between volcanic rocks that were formed at the tertiary age (Oligocene – Miocene). Based on the results of field observations, the research area is composed of rock units that become hostrock mineralization, namely andesitic breccia rock units in the west of the study area (**Fig. 5**). This andesitic breccia is dominated by a fine-grained matrix and fragments with an aphanitic texture. The rock characteristics on the outcrop scale have a gray-black color, the size of the fragments is 1-10 cm, the fragments consist of andesite igneous rock with angular – medium-angle grain shape, poor sorting, open packing, and a medium-sized sandstone base mass – coarse sand. Andesite fragments of fresh gray color, aphanitic grain, hypocrystalline, inequigranular, subhedral to anhedral grain shape, the visible mineral is quartz (**Fig. 2**).

Figure 1. Outcrop of the andesitic breccia rock.

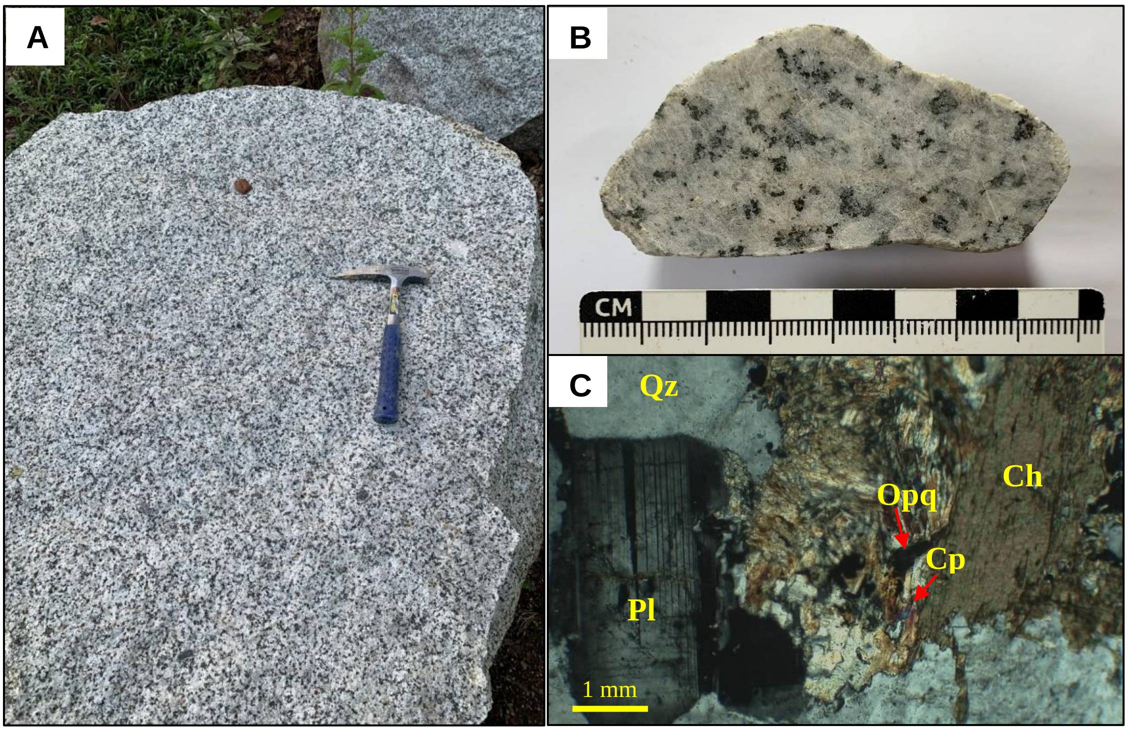

Figure 2. (A) Outcrop of granite **(B)** Handspecimen of granite **(C)** Photomicrographs of granite.Abbreviations: Qz: quartz, Cpx: clinopyroxene, Cpx: chlorite, Pl: plagioclase, Opq: opaque.

The Granite Intrusion Unit is located to the east of the andesite breccia unit and is located to the east of the Ketahun fault zone (**Fig. 5**). This unit is thought to have formed in the middle Miocene age, tectonic processes occurred in the Sumatra Fault zone which caused the emergence of a granite igneous rock intrusion zone (Tmgr) that broke through older rocks, namely andesite breccia rock units (Hulusimpang Formation). The characteristics of granite intrusive rocks are white to gray in color, with anhedral shape, massive and vesicular structure with coarse – grained texture with adjacent quartz and hornblenda mineral crystals (**Fig. 3.B**). The rock characteristics based on microscopic observations have characteristics of grayish white and brownish yellow, texture based on fine crystal size (0.1 – 2 mm), with euhedral – subhedral boundaries, and composed of quartz, plagioclase, clinopyroxene, chlorite and opaque minerals (**Fig. 3.C).**

2. Geological structures

Geological structure is the most important geological feature in the deposition of ore minerals and alteration in low-sulfidation epithermal gold deposits. The geological structure will distribute fluids into the surrounding rock and the movement of the structure generally results in a dilational environment that becomes ore mineral deposits [7]. Tectonic processes on the island of Sumatra related to subduction and magmatism began to occur, the first uplifting process started during the lower paleogene to the Plio-Pleistocene times. At the end of the Miocene, tectonic activity (orogenesis) began to occur which resulted in the rocks undergoing a deformation process, causing the formation of shear fractures and extensional fractures. The joints formed as a result of the orogenetic process cause magma to rise to the surface so that granite intrusions are formed, while tectonic processes take place so that the exposed granite rocks are also faulted by the Air Putih normal fault and the Ketahun fault. [1]. The tectonic process produces several geological structures that can be described in the research area. The geological structure is in the form of joints, namely shear fractures, brecciation, and dike. On field observations, shear fracture is characterized by the presence of paired joints, shaped like the letter X and do not have filler minerals (**Fig. 4.A**). The appearance of the structure of cracks / fractures formed in the rock due to a force acting on the rock (joints), which in this study is characterized by the presence of brecciation. The appearance of a dike or lava flow that cuts through rock layers is generally near vertical, formed by the injection of magma that fills into cracks / fractures in the earth (**Fig. 4.B**).

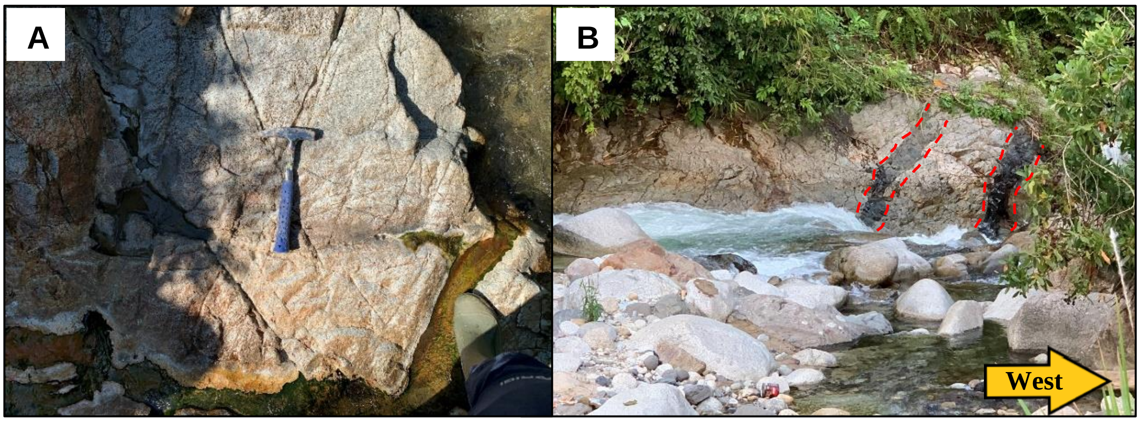

Figure 3. (**A**) Outcrop of the shear fracture and (B) Outcrop of the dike in the study area.

The research area is composed of two rock units that serve as hostrock mineralization, namely andesitic breccia rock units, this unit is widely distributed in the western part of the research location and granite rock units, these units are widely distributed in the eastern part of the study area. **(Fig. 5)**. The geological structure controlling mineralization is a dextral shear fault, which is part of the Ketahun fault.

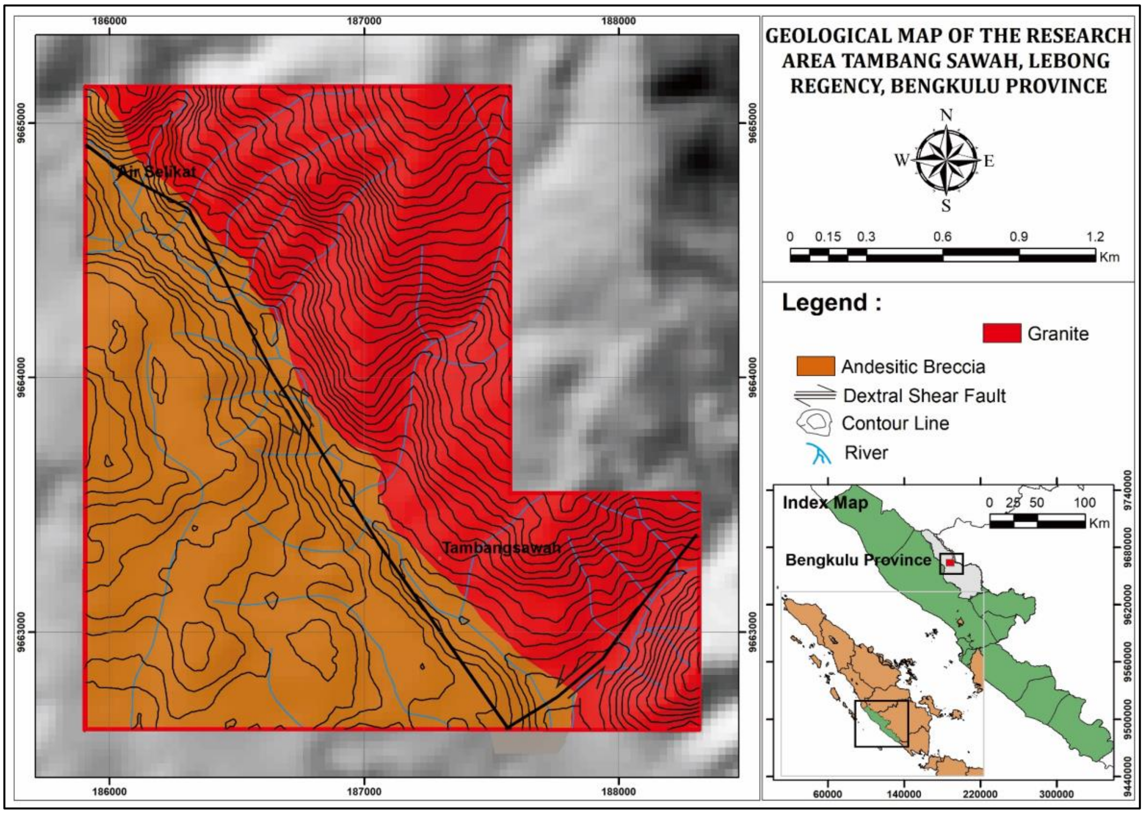

Figure 4. Geological map of the research area. Base maps and regional boundaries are taken from the Indonesian Earth Map (RBI) and the DEM raster is taken from DEMNAS data.

B. Ore Mineralization

1. Hydrothermal Alteration

Hydrothermal alteration in the study area is distinguished based on the presence of minerals that characterize each alteration. Hydrothermal alteration in low-sulfidation epithermal deposits will show lower levels further away from the veins, which indicates lower fluid reactivity due to decreasing temperature as the depth decreases and the distance from the veins increases [24]. Hydrothermal alteration in the study area was determined based on field observations, using petrographic analysis, XRD analysis. The types of alteration found in the study area include argillic alteration, silicification alteration, and propylitic alteration [16]. The argillic alteration zone is a zone characterized by the presence of clay minerals due to the H+ metasomomatism process and acid leaching at a temperature of 100ºC – 300ºC. This alteration is characterized by brownish gray and light gray rocks, with soft rock conditions because they are composed of dominant clay minerals, namely smectite (**Fig. 6.A**). Argillic alteration is characterized by the presence of clay minerals in the form of smectite, illite and kaolinite [14]. Silicification alteration is the most acidic alteration that causes side rocks to undergo a leaching process on non-resistant materials, leaving only resistant minerals such as quartz [6]. This alteration is characterized by reddish-brown rocks on the rock surface and has high hardness characteristics due to having an abundance of silica which is characterized by white rocks, consisting of massive silica and minerals quartz, plagioclase, illite/serisite, and alunite (**Fig. 6.C**). Propylitic alteration is characterized by the presence of epidote, chlorite, albite, carbonate, sericite, montmorillonite, apatite, anhydrite, ankerite, hematite, pyrite, chalcopyrite minerals [12]. The characteristic mineral in this alteration that can be found is chlorite (**Fig. 6.B** dan **6.D**). There is little clay mineral that replaces plagioclase minerals. The presence of clay minerals in the form of illite / sericite is the result of overprinting by silicification alteration.

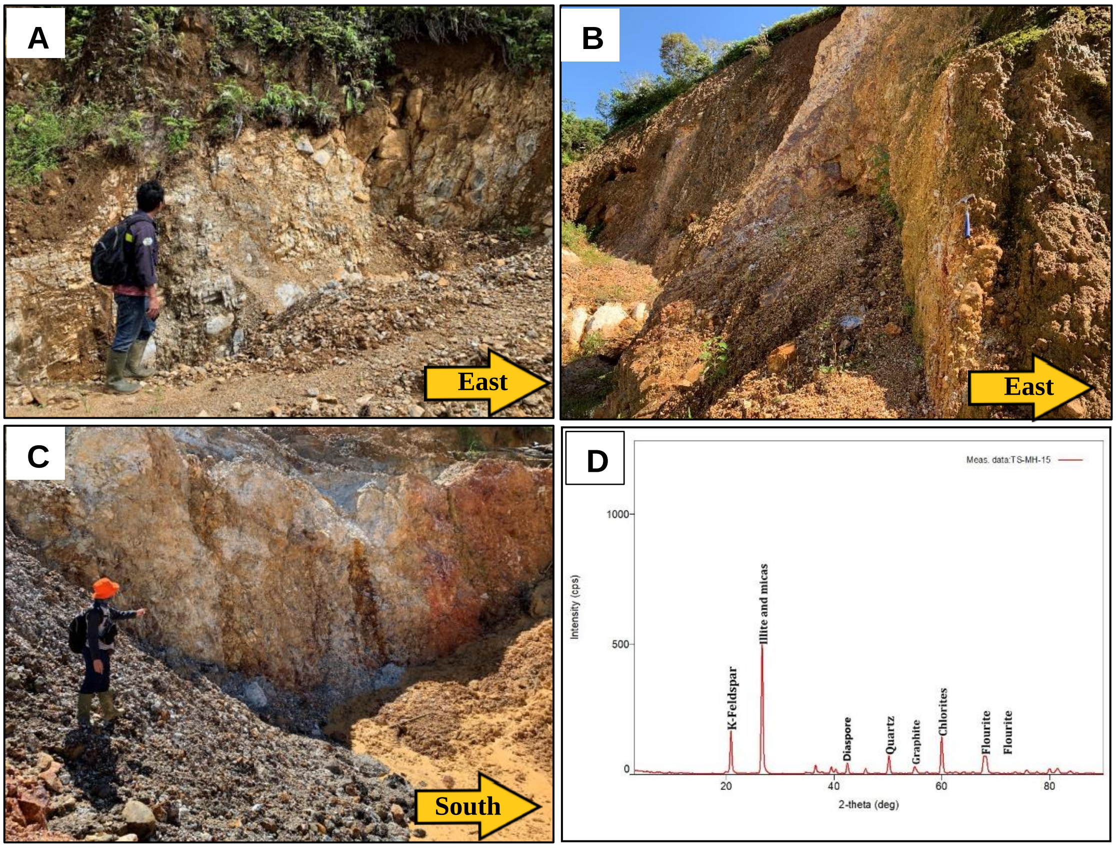

Figure 5. (A) Outcrop of the argillic-altered rock **(B)** Outcrop of the propylitic alteration rock **(C)** Outcrop of the silicification altered rock **(D)** The results of XRD analysis on rock samples are characterized by the presence of minerals that characterize propylitic alteration in the form of chlorite and illite minerals.

2. Gold-Bearing Quartz Veins

The presence of veins in rocks is important for understanding mineralization in rock bodies that occur in a hydrothermal system [9] of course for success in the exploration of mineral resources in the mining industry. Based on the megascopic and microscopic observations of rocks, the materials that make up the veins are silica minerals, sulfide minerals and carbonate minerals. [15] To classify the texture of quartz veins in epithermal deposits. Then the texture of the veins based on megascopic observations consists of colloform banded, cockade-crustiform, moss, and brecciated texture (**Fig. 7** and **8**). In this vein-type low-sulfidation epithermal deposit, gold is generally free gold both as electrum and as native gold [13].

During field observations and rock observations, there was a vein type with primary growth texture found at the study site, which indicated precipitation or growth in the early stages of crystallization in open space [15]. In the early stages of mineralization, veins are formed (generally in the form of quartz veins, with the characteristic minerals in the form of quartz, pyrite and sphalerite) as a result of filling and crystallization of hydrothermal fluids in the fracture, the filling is evidenced by the discovery of the texture of filling quartz veins, especially in the form of *cockade-crustiform*, and *colloform banded* (**Fig. 8.C** dan **8.D**).

Mapping/field observations and ore microscopic observations show that the ore minerals present in the study area include pyrite (FeS_2), chalcopyrite ($CuFeS_2$), covelite (CuS), sphalerite (ZnS), galena (PbS), carbonate mineral namely malachite ($Cu_2(OH)_2CO_3$) and gangue mineral quartz (SiO_2) dan plagioclase (($NaAlSi_3O_8$ – $CaAl2Si_2O_8$). Sphalerite (ZnS) can be identified from megascopic observations by its darker color than galena and its sub-metallic luster (**Fig. 8.C** and **8.D**). Pyrite (FeS2) is easy to identify because of its large size and abundance and can be found in various hydrothermal veins in the study area. Pyrite can be identified megascopically by its physical properties, which are cubic and disseminated, pale yellow color and has a black streak (**Fig. 9.A** dan **9.B**).

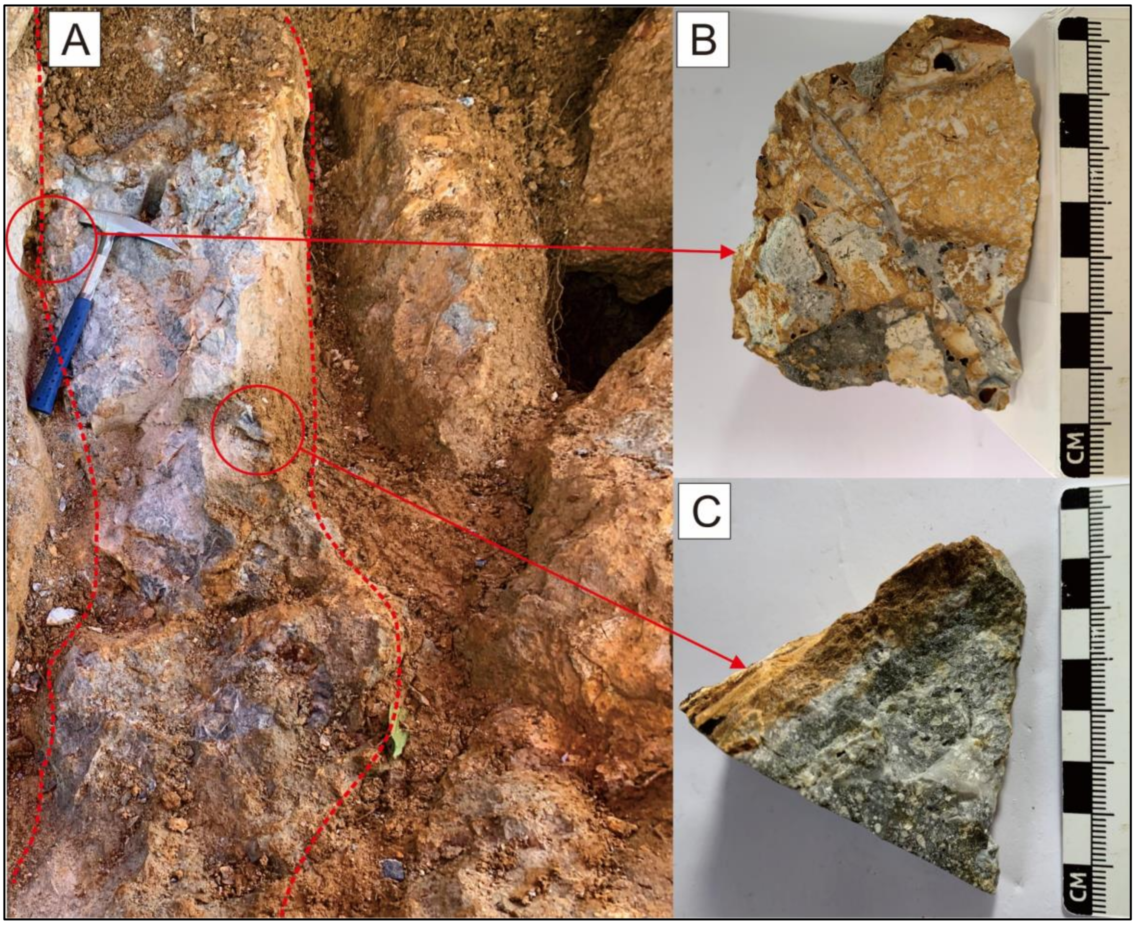

Figure 6. (A) Outcrop of the gold-carrying quartz veins in the artisanal mining area, **(B)** handspecimen of the LS-epithermal veins showing characteristics of brecciated textured vein, **(C)** moss textured vein.

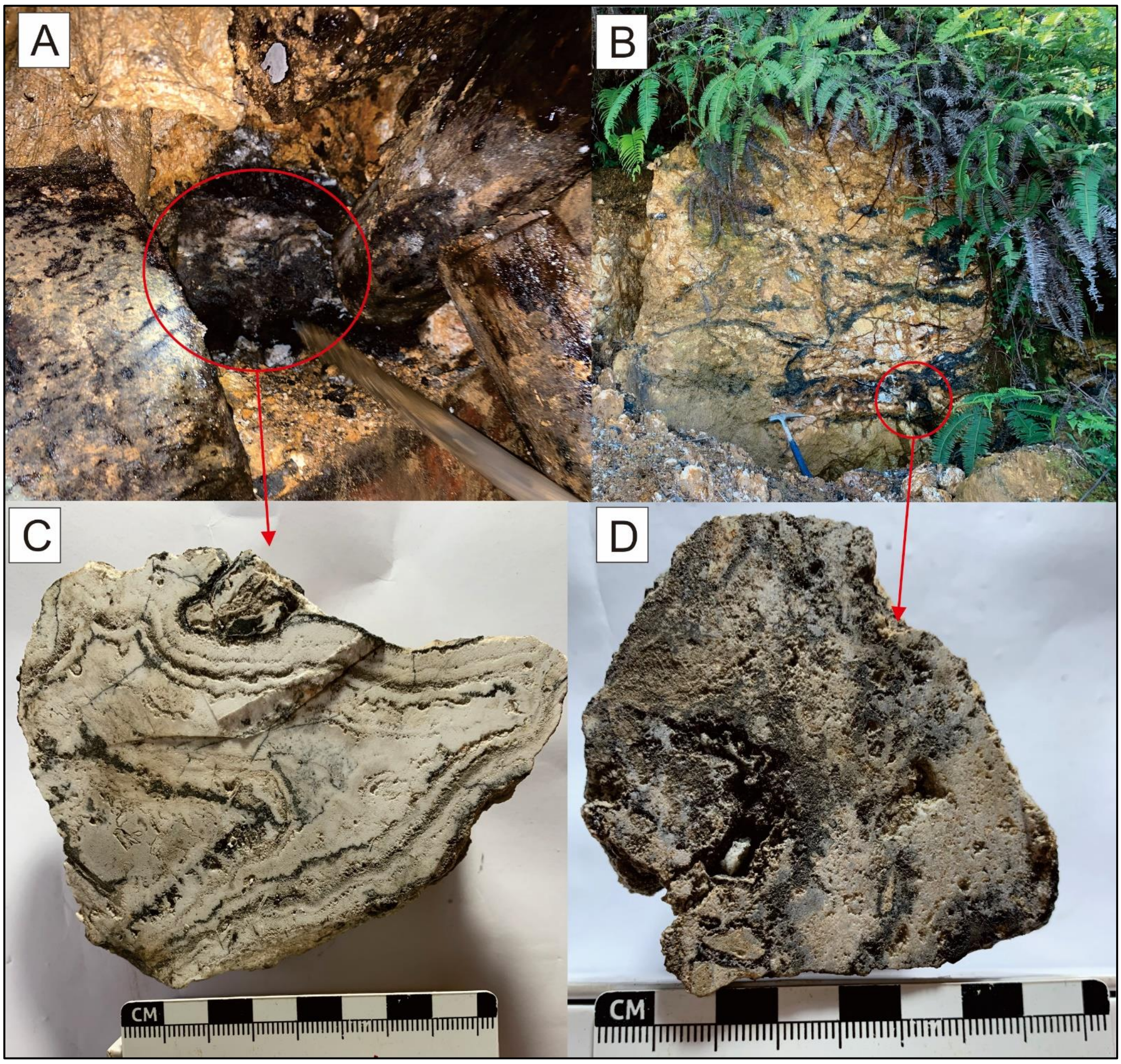

Figure 7. (A) (B) Outcrop of the gold-bearing quartz veins on the front wall and in the artisanal mining tunnels, **(C)** handspecimen of the LS-epithermal veins showing characteristics of colloform banded textured vein, **(D)** cockade-crustiform textured vein.

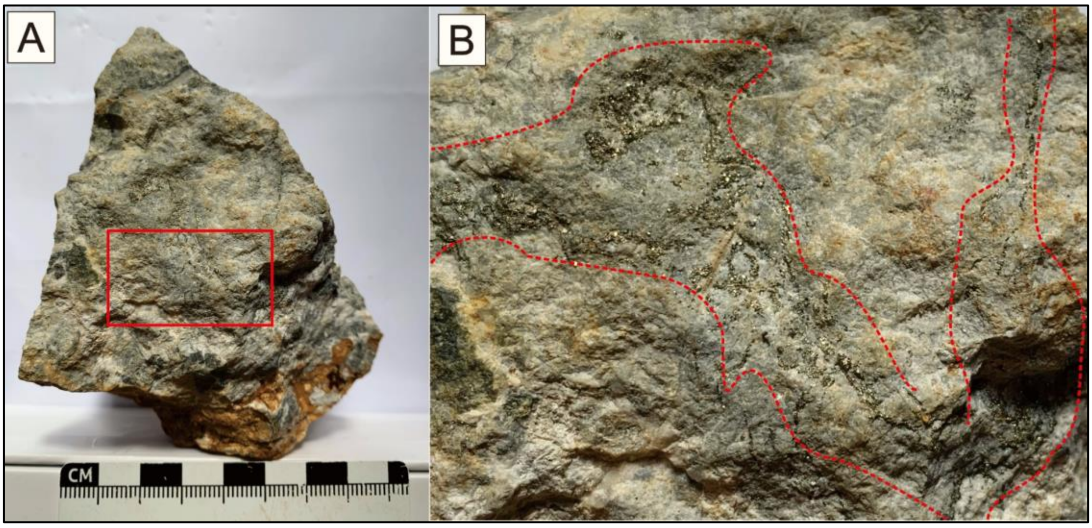

Figure 8. (A) Handspecimen of the LS-epithermal veins showing of pyrite minerals. **(B)** Inset of pyrite mineral

Microscopically, chalcopyrite can be identified by its golden yellow color, subhedral shape, weak anisotropy, lack of pleochroism, moderate reflectance, weak bireflectance, and dark gray internal reflectance (**Fig. 10.A**). Microscopically, pyrite mineral has a yellowish white color, no pleocroism, subhedral shape, isotropic, and moderate reflectance (**Fig. 10.B**). Covelite mineral (CuS) is Cu carrier sulfide mineral which is a product of supergene enrichment. On microscopic observation with parallel nickel, the covelite has a light blue color, a subhedral shape, indicating the presence of pleocroism, showing of the crossed nicol has a blue interference color and also covelite crystallization simultaneously with pyrite (**Fig. 10.C**). The mineral galena is replaced by the mineral sphalerite (**Fig. 10.D**).

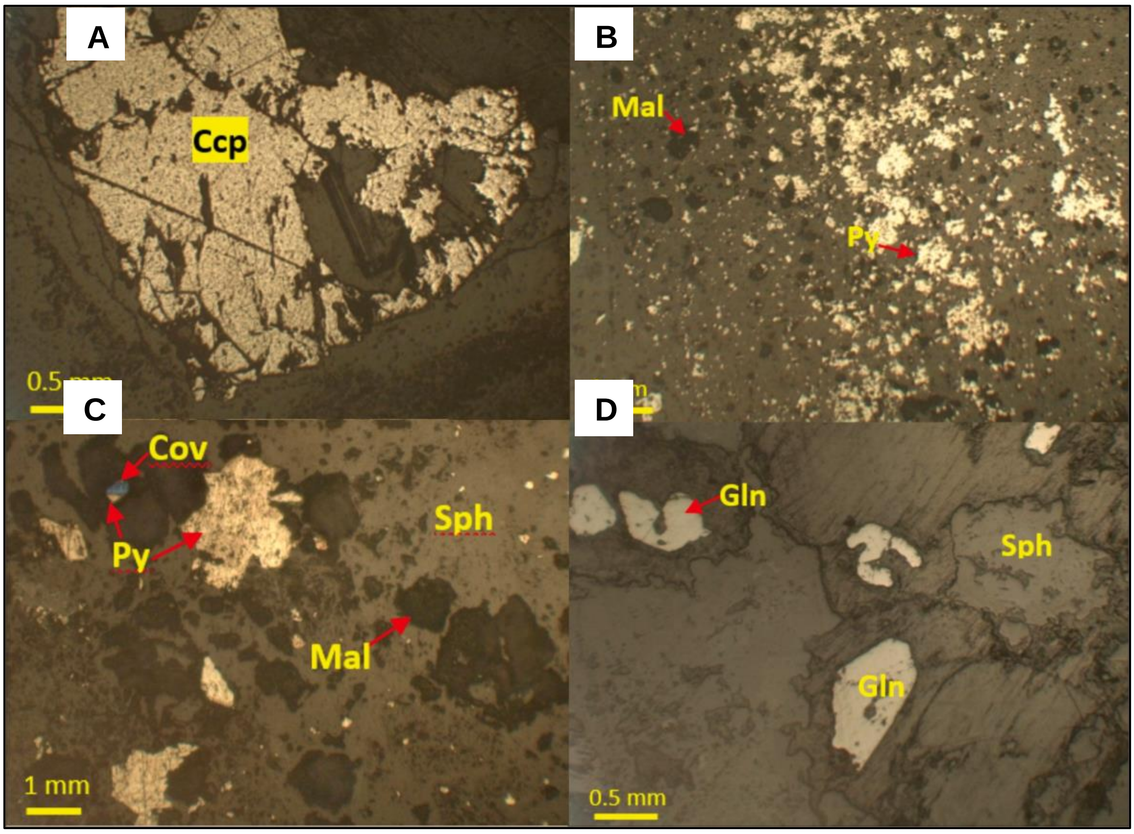

Figure 9. (A) Photomicrographs of chalcopyrite mineral **(B)** Photomicrographs of mineral pyrite with disseminated texture **(C)** Photomicrographs of pyrite minerals and covellite minerals showing intergrowth textured **(D)** Photomicrographs of mineral galena is replaced by the mineral sphalerite, Abreviasi: Py: pyrite, Ccp: chalcopyrite, Sph: sphalerite, Cov: covelite, Gln: galena, Mal: malachite.

Elemental levels of gold (Au), silver (Ag), copper (Cu), lead (Pb), zinc (Zn) are known from the geochemical analysis of Fire Assay – Atomic Absorbtion Spectometry (FA-AAS) showing that the gold content in rocks and veins varies greatly with an average 4,8 ppm with colloform banded and cockade-crustiform vein textured (**Fig 8.C** and **8.D)** with a propylitic alteration type.

C. Discussion

There are two geological aspects that play a role in the alteration and mineralization of ore in low sulfidation epithermal deposits, namely lithology and geological structure, which are related to the permeability function, geological structure and this type of lithology will become deposits of an ore mineral [18]. In the study area, alteration and mineralization processes are related to the neogene magmatic arc in the Oligocene – Miocene Hulusimpang Formation [8]. The research area is composed of two rock units that serve as hostrock mineralization, namely andesitic breccia rock units and granite rock units. This andesitic breccia is dominated by a fine-grained matrix and fragments with an aphanitic texture. Rock characteristics on the outcrop scale have a gray-black color. On the surface, it is mostly covered by volcanic rocks around the Tambang Sawah [2], and andesite rocks are blackish gray to brownish in Oligocene – Miocene age and belong to the Hulusimpang Formation [22]. The Hulusimpang Formation consists of lava, volcanic breccia, and altered tuff, andesite to basalt composition [11]. The granite unit is estimated to have formed at the middle Miocene age, tectonic processes occurred in the Sumatra Fault zone which caused the emergence of an igneous granite intrusion zone (Tmgr) that broke through older rocks, namely andesitic breccia rock units (Hulusimpang Formation). Granite rocks break through the breccia rock unit inserts of lava and tuff (Hulusimpang Formation) of Oligocene – Early Miocene age [1], this is also the case with [11] revealing that the granite rocks found in the Tambang Sawah are Miocene. Geological structure is the most important geological feature in the deposition of ore minerals and alteration in low sulfidation epithermal gold deposits. The geological structure will distribute fluids into the surrounding rock and the movement of the structure generally results in a dilational environment that becomes ore mineral deposits [7]. The geological structure that developed in the Lebong area shows the main structure, namely the Ketahun Fault which has a northwest-southeast (NW-SE) trend [11] [21], which is part of the Sumatran Fault segment [17]. The general structure found in the form of faults. This fault is part of the Sumatran fault zone which leads northwest - southeast. The characteristics are in the form of cliffs, and steep valleys, and can be seen from the lineaments [22]. This fault is found along the Air Putih River in a northwest-southeast direction, this fault breaks the Sisivan Lava and Tuff Breccia Unit (Hulusimpang Formation) and Granite Rock Unit [1]. The Tambang Sawah area is a separate mineralization, namely in the form of intrusive rocks against andesitic volcanic rocks, so that the structure in the study area is quartz veins originating from extensional and fractures [2].

The characteristics of the epithermal deposits in the study area are known from the characteristics of the hostrock, the texture of the ore minerals, the alterations found and the dominant sulfide minerals [13]. The Tambangsawah area has source rocks in the form of andesitic breccia rocks and granite rocks. The ore texture in the study area consists of primary textures, one of which is the open space deposition, disseminated and intergrowth. Alterations found in the study area include argillic, silicification, and propylitic alterations. The type of epithermal deposit in the study area is classified as an epithermal deposit with a low sulfidation type of deposit (cf [13][20]), with some characteristics of low-sulfidation epithermal deposits in the Tambang Sawah area characterized by propylitic alterations found in quartz and carbonate minerals, namely malachite minerals and dominated by illite and chlorite. The mineral association of pyrite is indeed abundant but is supported by the presence of the mineral’s sphalerite, galena, and chalcopyrite. Au ore minerals are positively correlated with Ag, Cu, Pb, Zn elements. The type of mineralization formation of low sulfidation deposits is found along hydrothermal veins as well as crustiform vein textures, and brecciated vein textures. The gangue minerals in the research area are quartz, plagioclase, sericite, and clay minerals. Based on the characteristics of these epithermal deposits, it is known that the Tambang Sawah area deposits are low sulfidation epithermal deposits. The Tambang Sawah area is associated with volcanic breccia, lava, basalt [11], deposits of quartz veins, brecciated bodies, comb texture, crustiform, colloform, moss and brecciated textured. Hydrothermal alteration with the presence of clay minerals, sericite, illite and chlorite. Gangue minerals quartz, plagioclase, sericite, and clay minerals. Sulphide minerals pyrite, sphalerite, galena, chalcopyrite and covelite.

IV. CONCLUSION

The Tambang Sawah area is composed of two rock units that serve as hostrock mineralization, namely andesitic breccia rock units and granite rock units. Geological control that affects mineralization in the study area is the geological structure in the form of joints, namely shear fracture, brecciation, dike and faults, namely Ketahun fault which produces shear zones. Hydrothermal alteration present at the study site is a typical type of alteration with low sulfidation epithermal gold deposits namely argillic, silicified, and propylitic. Hydrothermal alteration with the presence of clay minerals, sericite, illite and chlorite. Gangue minerals quartz, plagioclase, sericite, and clay minerals. The sulfide minerals present at the study site consist of pyrite, chalcopyrite, covelite, sphalerite, and galena with a vein texture colloform, lattice bladed, crustiform, moss, comb and brecciated textured. The level of gold in rocks and veins varies greatly with an average 4,8 ppm with colloform banded and cockade-crustiform texture on the propylitic alteration type.

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REFERENCES

[1] R. Agustina, "Geologi dan studi petrogenesa batuan beku granit daerah Tambangsawah dan sekitarnya, Kecamatan Pinangbelapis, Kabupaten Lebong, Provinsi Bengkulu," *Jurnal Online Mahasiswa (JOM) Bidang Teknik Geologi*, vol. 1, no. 1, 2019.
[2] I. R. Arief, and P. Madya, "Cebakan emas primer di Lebong Tandai Kabupaten Bengkulu Utara Provinsi Bengkulu. Buletin Sumber Daya Geologi," vol. 4, no. 3, pp. 14-22, 2009
[3] N. T. Arndt, L. Fontbote, J. W. Hedenquist, S. Kesler, J. F. H. Thompson, dan D. G. Wood, "Geochemical perspective: future global mineral resources," Washington DC. European Association of Geochemistry, 2017.
[4] A. J. Barber, M. J. Crow, J. Dan Milsom, "Sumatra: geology, resources and tectonic evolution. london: the geological society," *Geological Society Memoirs 31*, The Geological Society Publishing House, Bath BA1 3JN, UK. 2005.
[5] J. C. Carlile and A. H. G. Mitchell, "Magmatic arcs and associated gold and copper mineralization in Indonesia: in van Leeuwen, T.M., Hedenquist, J.W., James, L.P., and Dow, J.A.S., eds., Mineral Deposit of Indonesia, Discoveries of the Past 25 Years: Journal of Geochemical Exploration, Vol. 50, pp. 91-142, 1994
[6] G. J. Corbett and T.M. Leach, "Southwest Pacific Rim gold-copper systems: structure, alteration, and mineralization," *Workshop manual*,18p, 1996.
[7] G. J. Corbett and T.M. Leach, "Southwest pacific gold – copper systems: structure, alteration and mineralization, economic geology, special publication 6," *Society of Economic Geologists*, 238p. 1997.
[8] M. J. Crow and T. M. Van Leeuwen, "Metallic mineral deposits. Sumatra Geology, Resources and Tectonic Evolution," *Published by Geological Society*, pp. 174-174, 2005.
[9] G. Dong, G. Morrison, and S. Jaireth, "Quartz textures in epithermal veins, queensland – classification, origin, and implication," *Economic Geology*, vol. 90, pp. 1841 – 1856, 1995.
[10] F. L. Fahmi, "Kontrol struktur geologi terhadap sistem hidrotermal di Lebong Utara, Bengkulu," Doctoral dissertation, Universitas Gadjah Mada, 2017.
[11] S. Gafoer, T. C. Amin, and R. Pardede, "Geological map of the Bengkulu quadrangle, Sumatera," Geological Reseach and Development Centre. 1992.
[12] C. Gifkins, W. Herrmann, and R. Large, "Altered volcanic rocks – A guide to description and interpretation," Centre Ore Depos Res, Univ Tasmania, Hobart, 2005.
[13] J. W. Hedenquist, A. R. Arribas, and E. Gonzalez-Urien, "Exploration for epithermal gold deposits," *Reviews in Economic Geology*, vol. 13, pp. 245–277, 2000.
[14] A. Idrus and W. Hermansyah, "Karakteristik mineralisasi bijih emas pada prospek Hargosari, Kecamatan Tirtomoyo, Kabupaten Wonogiri, Provinsi Jawa Tengah," *Kurvatek*, vol. 6, no. 1, pp. 31-40, 2021.
[15] G. Morrison, G. Dong, and S. Jaireth, "Textural Zoning in Epithermal Quartz Veins, Klondike Exploration Services, Townsville. 1990. 35p.
[16] F. Pirajno, "Hydrothermal processes and mineral systems," Springer Science+Business Media: Australia, pp.103, 2009.
[17] K. Sieh dan D. Natawidjaja, "Meotectonics of the sumatra fault," *Journal of Geophysical Research*, Indonesia, 2000.
[18] S. F. Simmons, N. C. White and D. A. John, "Geological charasteristic of epithermal precious and base metals," Economic Geology 100th, Anniversary Volume, pp 485 – 522, 2005.
[19] Soetoto dan A. Setianto, "Buku ajar geologi citra penginderaan jauh," Jurusan Teknik Geologi, Fakultas Teknik, Universitas Gadjah Mada, Yogyakarta, 171p, 2005.
[20] H. N. H. Sudarmadi, "Geologi, Alterasi, Mineralisasi dan Pengayaan Sekunder pada Endapan Emas Epitermal Sulfidasi Tinggi di Bukit Seruyung, Kecamatan Sebuku, Kabupaten Nunukan, Provinsi Kalimantan Utara," Doctoral dissertation, Universitas Gadjah Mada), 2017.
[21] N. Suwarna, Suharsono, S. Gafoer, T. C. Amin, Kusnama and B. Hermanto, "Peta geologi lembar Sarolangun, Sumatera," Puslitbang Geologi dan IAGI Pusat, Bandung, 1992.
[22] Z. Tain, "Pendataan dan evaluasi pemanfaatan bahan galian pada daerah bekas tambang dan wilayah PETI di daerah Lebong Utara, Kab. Rejang Lebong Provinsi Bengkulu," Subdit Konservasi. DIM. Bengkulu, 2005.

[23] R. W. Van Bemmelen, "The Geology of Indonesia, " vol. 1A. The Hague: Martinus Nijhof, 1949.
[24] N. C. White and J.W. Hedenquist, "Epithermal Gold Deposits: Styles, Characteristic, and Exploration," *SEG Newsletter*, 23 (1): 9-13.