THE METAMORPHIC ROCK-HOSTED GOLD MINERALIZATION AT BOMBANA, SOUTHEAST SULAWESI: A NEW EXPLORATION TARGET IN INDONESIA
(MINERALISASI EMAS PADA BATUAN METAMORF DI BOMBANA, SULAWESI TENGGARA: TARGET BARU EKSPLORASI DI INDONESIA)

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Abstract

Placer gold has been discovered in Bombana, SE-Sulawesi, Indonesia. The placer gold is not associated with volcanic rock-related gold deposits. This paper discusses the primary gold mineralization as the source of the placer gold. The placer gold is possibly derived from gold-bearing quartz veins hosted by Pompangeo Metamorphic Complex (PMC). Pyrite, chalcopyrite, cinnabar, stibnite and tripuhyite are present. Sheared, segmented vein varies in thickness from 2 cm to 2 m. The veins contain erratic gold in various grades from below detection limit (0.005 g/t) to 134 g/t. At least three generations of veins are identified. The first is parallel to the foliations, the second crosscuts the first generation of veins/foliations, and the third is of laminated deformed quartz+calcite veins at the late stage. The first veins are mostly massive to crystalline, occasionally brecciated and sigmoidal, whereas the second veins are narrower than the first and relatively brecciated. Gold grades in the second and third veins are relatively higher than that in first veins. Fluid inclusion study of quartz veins indicates abundant H2O-NaCl and a small amount of H2O-NaCl-CO2 inclusions. Temperature of homogenization (Th) and salinity of the first vein vary from 184.7 to 245.3 ºC and 5.26 to 9.08 wt.% NaCl eq., respectively. The second generation vein was originated at Th of 132.1-283.4 ºC and salinity of 3.55-5.86 wt.%NaCl eq., whereas the third generation vein formed at lowest Th varying from 114 to 176ºC and less saline fluid at salinity range between 0.35 and 4.03 wt.% NaCl eq. Gold is mainly identified in the form of 'free gold' among silicate minerals. Mineralogically, gold is closely related to cinnabar, stibnite, tripuhyite and possibly minor arsenopyrite. Metamorphogenic gold deposits would be the new target of gold exploration in Indonesia.

Keyword: Gold mineralization, orogenic-type, Bombana, Southeast Sulawesi, Indonesia

S a r i

Endapan emas letakan (placer) ditemukan di Bombana, Sulawesi Tenggara, Indonesia. Berdasarkan geologi regional, endapan letakan tersebut tidak terkait dengan endapan emas primer pada batuan induk berupa vulkanik. Tulisan ini mendiskusikan mineralisasi emas primer sebagai sumber dari endapan letakan (sekunder) di daerah tersebut. Emas letakan tersebut kemungkinan berasal dari urat-urat kuarsa pembawa emas yang terdapat dalam batuan metamorf (sekis mika, filit dan meta sedimen) dari Pompangeo Metamorphic Complex (PMC). Mineralisasi dicirikan oleh pirit, kalkopirit, cinnabar, stibnit dan tripuhyit. Urat kuarsa secara umum tergerus, tersegmentasi memiliki ketebalan antara 2 cm sampai 2 m. Kadar emas dalam urat sangat bervariasi dari di bawah ambang batas (0,005 g/t) sampai 134 g/t. Paling tidak ada 3 generasi urat yang teridentifikasi. Urat generasi pertama paralel dengan foliasi batuan metamorf, urat generasi kedua memotong urat pertama dan foliasi, serta urat generasi ketiga merupakan urat kuarsa+kalsit terlaminasi yang terbentuk pada tahap akhir dari pembentukan urat di daerah penelitian. Urat pertama umumnya massif sampai kristalin, kadang-kadang terbreksiasi dan sigmoidal, sedangkan urat kedua umumnya lebih tipis dan lebih terbreksiasi, tapi kadar emasnya lebih tinggi dari urat pertama. Studi inklusi fluida (FI) terhadap urat kuarsa

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menunjukan kelimpahan inklusi fasa H2O-NaCl dan sedikit inklusi H2O-NaCl-CO2. Temperatur homogenisasi (Th) dari FI urat pertama bervariasi dari 184,7-245,3 ºC dengan salinitas 5.26-9.08 wt.% NaCl eq. Urat generasi kedua menunjukan Th FI antara 132.1 dan 283.4 ºC dengan salinitas 3.55-5.86 wt.%NaCl eq., sedangkan FI urat ketiga memiliki Th terrendah 114 - 176ºC dengan salinitas rendah (0.35 and 4.03 wt.% NaCl eq). Emas umumnya teridentifikasi sebagai 'free gold' di antara kristal mineral silika khususnya kuarsa. Emas berasosiasi dengan cinnabar, stibnit, tripuhyit dan mungkin sedikit arsenopirit. Endapan emas metamorfogenik dapat menjadi target baru pada kegiatan eksplorasi emas di Indonesia.

Kata kunci : Mineralisasi emas, endapan tipe orogenik, Bombana, Sulawesi Tenggara, Indonesia.

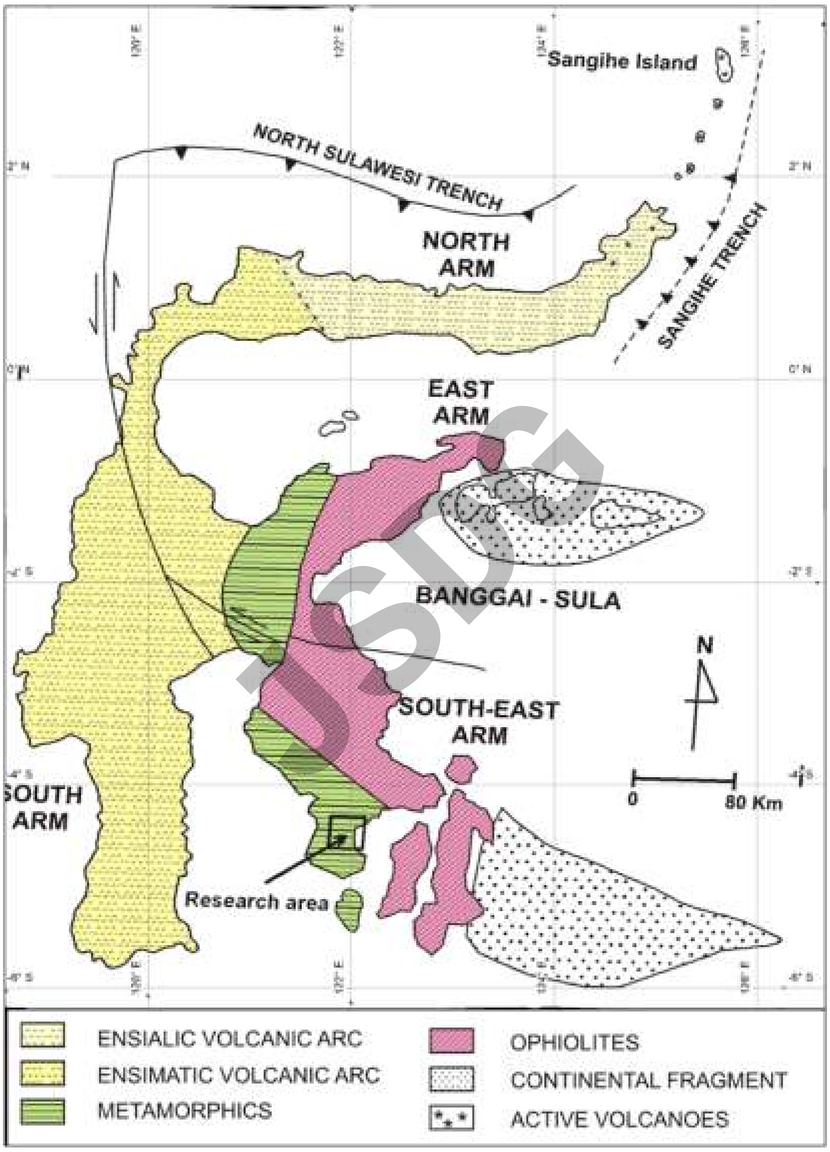

Figure 1. Location map of study area in Bombana Regency, Southeast Sulawesi (squared area), plotted on the Sulawesi geological map from Hamilton, 1979.

Introduction

Currently, in Indonesia gold has mostly been mined from volcanic-hosted hydrothermal deposits including epithermal type e.g. Pongkor in West Java (Basuki *et al*., 1994; Warmada, 2003), Gosowong in Halmahera Island (Carlile *et al*., 1998; Gemmell, 2007), skarn type e.g. Erstberg, Big Gossan, Kucing Liar, Deep Ore Zone (DOZ) in Papua (e.g. Mertig et al., 1994), and porphyry type e.g. Batu Hijau in Sumbawa Island (Meldrum *et al*., 1994; Idrus *et al*.,

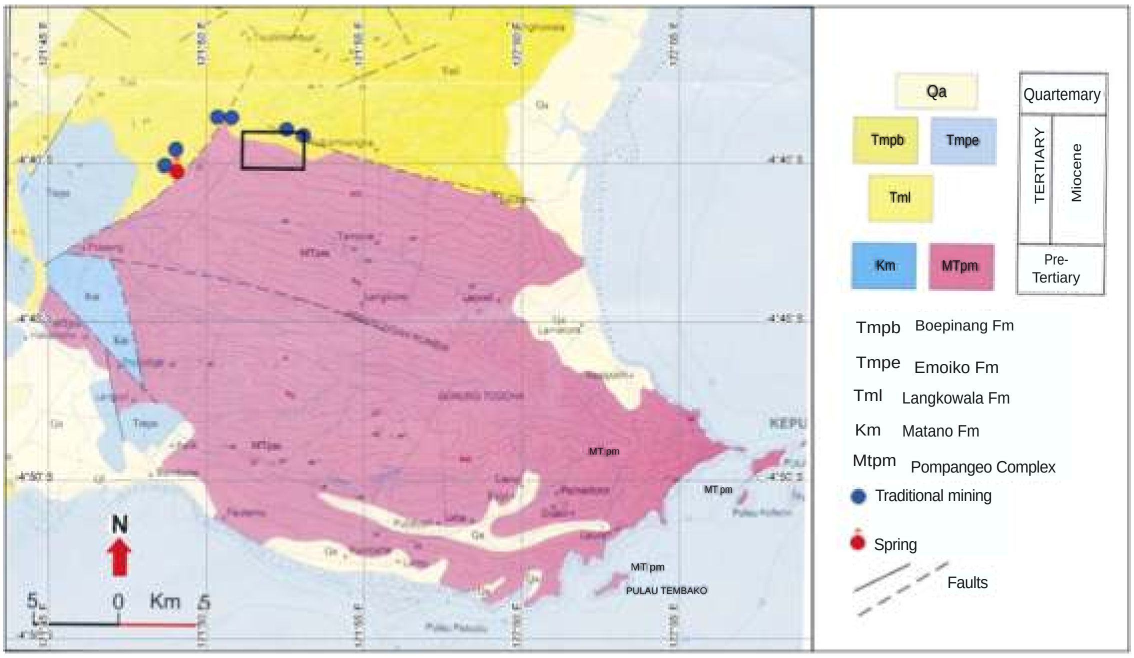

Figure 2. Geological map of Langkowala area occupied by Paleozoic metamorphic rocks (Pompangeo Complex; Mtpm) in the south (Wumbubangka and Rumbia mountain range), which is unconformably underlain by Langkowala Formation (Tml) (Modified from Simandjuntak *et al*., 1993). Squared area indicates the location area of this study.

2007; Imai & Ohno, 2005). In Sulawesi, gold mineralization is also predominantly related to volcanic rocks, which is extended along the western and northern Neogene magmatic arcs of the island (Carlile et l., 1990; Carlile & Mitchell, 1994; Idrus, 2009).

However, gold has also been found in southeast arm of Sulawesi, particularly in Langkowala area, Bombana Regency (Fig. 1, 2), in the form of placer and paleoplacer. Gold grains were firstly discovered in stream sediment of Sungai (River) Tahi Ite in 2008, and after that, more than 20,000 traditional gold miners have worked in the area (Kompas Daily, September 18, 2008). During January 2009, the number of traditional gold miners in Bombana Regency increased significantly and reaching the total of 63,000 people (Surono & Tang, 2009). The secondary gold is not only found in recent stream sediment (placer), but also occurred within Mio-Pliocene sediments of Langkowala Formation (paleoplacer). The genetic type of primary source of the Bombana placer/paleoplacer gold is thought to be hosted by Pompangeo Metamorphic Complex (PMC), but is still in controversy and open for discussion.

This paper describes the result of preliminary study on possible primary mineralization type as the source of the Langkowala (Bombana) placer gold, based the field investigation and data analysis in the mining concession area of PT Panca Logam Utama and surrounding area, that is located in Wumbubangka at the northern flank of the Rumbia mountain range (Fig. 2). The study has been emphasized on some key characteristics of the primary deposit including host rock petrology, quartz vein texture and structure, hydrothermal alteration, ore mineral and chemistry and mineralizing hydrothermal fluid properties. It is expected that the result of this study would be important to better understand the genetic model of Bombana gold mineralization, and would be useful in designing future exploration strategy for gold deposits in Indonesia.

Geological Setting

Langkowala area where the placer gold found is characterized by wavy-flat morphology, and it is crosscut by some major rivers including Langkowala River, Lausu River, Lebu River and Pampea River. Langkowala area is located between Mendoke Mountain in the north and Rumbia Mountain in the south.

The description on the rock formations below in particular the relative age is referring to Simanjuntak *et al*. (1993), unless otherwise stated differently, but also combined with the author field observation for the rock types. The area is subsequently occupied by metamorphic rocks (Pompangeo Complex, Mtpm) consisting of mica schist, quartzite, glaucophane schist and chert. The metasediments and metamorphic rocks are of Permian-Carboniferrous in age and occupy the Mendoke and Rumbia

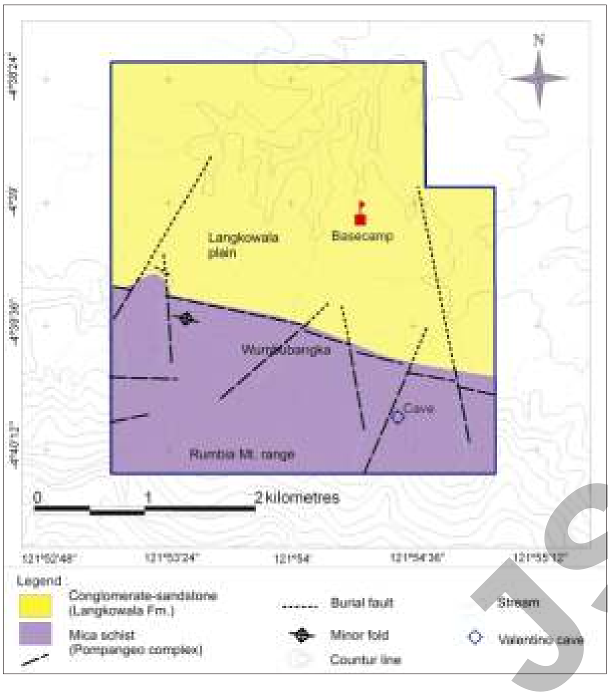

Figure 3. Local geological map of Wumbubangka area at the northern flank of Rumbia metamorphic mountain range.

Mountains. Mica schist and metasediments particularly meta-sandstone and marble are commonly characterized by the presence of quartz veins/veinlets with various width up to 2 meters, containing gold in some places. This metamorphic basement rock is not conformably overlain by Emoiko Formation (Tmpe), which is composed of limestone-marl-sandstone intercalation; and Boepinang Formation (Tmpb), which is composed of sandy claystone, sandy marl and sandstone. The Emoiko and Boepinang Formations were reported having Pliocene age. These two rock formations are conformably overlain by Langkowala formation. Mio-Pliocene Langkowala Formation (Tmls) consisting of conglomerate and sandstone. This Formation is a part of the Sulawesi Molasses, which were firstly described by Sarasin & Sarasin (1901) in Surono & Tang (2009). In some areas, the Langkowala Formation is also directly unconformably underlain by the Mesozoic metasediments and metamorphic rocks.

Structural geology in the area is interpreted from topographic lineaments and field data. Interpretative E-W-trending faults, which are relatively parallel to the foliation attitude of the metamorphic rocks apparently acts as mineralization-hosting shear zones that formed first generation of quartz veins/ reefs in the area. The NE trending faults are thought to be the main control of the formation of second generation of quartz veins (that cross-cut the foliations). The regional geological map of Bombana (including Langkowala)and local geological map are shown in Fig. 2 and Fig. 3, respectively.

Langkowala Placer Gold

Gold grains were observed in both stream sediment of the present-day active rivers and in the Tertiary sedimentary rocks of Langkowala Formation. A large number of traditional gold “miners” have been worked by digging 3-6 m vertical pits/shafts of unconsolidated sediment of the Langkowala Formation and also by panning the active sediment to chase the native gold grains. Some miner groups have combined panning works with sluicing box method for better recovering gold. The distribution of gold working areas indicates that the placer gold is distributed not so far from metamorphic mountain range. A relatively short distance of gold transportation is consistent with the subrounded-angular form of gold grains panned in this area (Makkawaru & Kamrullah, 2009). Preliminary data also exhibits that the abundance of gold grains decreased as its distance from the metamorphic mountain range increased.

Gold is also discovered in the colluvial materials along Wumbubangka mountain slope and isolated valleys of the mountain range. Geochemical analysis using Fire Assays and AAS (Atomic Absorption Spectrometry) of 18 stream sediment samples (minus 160 mesh) from Langkowala area indicates that gold (Au) grade is relatively low ranges from 0.005 to 0.033 g/t, with average of 0.01 g/t Au (recalculated from Prihatmoko *et al*., 2010). However, other laboratory analyses of three selected stream sediment samples from the studied area

Table 1. Bulk-ore chemistry of stream sediment (SS) and pan concentrate (PC) containing abundant cinnabar grain taken from the Langkowala placer, Bombana.

Sample codes	Elements (g/t)							
	Cu	Pb	Zn	Ag	Au	Hg	As	Sb
SS-01	47	88	105	3	18	na	240	160
SS-02	60	69	74	2	10	na	325	640
PC-cinnabar	81	64.4	11	117	913.5	19.97	na	na

na = not analyzed

exhibit significant gold grades i.e. 18 g/t, 10 g/t and 913.5 g/t Au, respectively (Table 1). The third sample that this first generation of quartz vein is crosscut by quartz veinlets/ stockwork/stringers. The second quartz vein generation crosscut the first generation quartz veins and as well as the foliation of host-rocks (Fig. 4c); whereas the third vein generation is characterized by deformed laminated quartz+calcite vein, which is interpreted as the latest stage of vein formation in the studied area (Fig. 4d).

The first generation of quartz veins (that are parallel to foliation) are commonly 2 cm to 2 m in width, whereas the second phase quartz veins have commonly less than 10 cm in width. The third generation quartz veins hosted by metasediment are mostly parallel to the 'laminated' structures, identified in zones up to 15 meters wide. The first generations of quartz veins are mostly massive to crystalline, occasionally brecciated and sigmoidal, whereas the second quartz veins are narrower than the first and relatively brecciated. In addition, as observed by Prihatmoko *et al*. (2010), druzy/sugary and some pseudomorph bladed carbonate textures have also been recognized associated with quartz veins/reefs cross cutting foliation (Fig. 4e). In the Onggomate hill the veins formed a breccias zone composed of quartz as matrix, massive to crystalline, crackle to mosaic, with mica schist and phyllite fragments. In the Roko-Roko hill quartz veins (1-30 cm) hosted by mica schist and metasediment are commonly massive to crystalline quartz (druzy textures) with pseudomorph bladed carbonate textures. Therefore, at least 2 later stages of veinings (after the first generation veinings) could be identified, including (1) vein breccias and (2) later quartz veinlets, 1-10 mm, which are commonly crystalline and containing native gold (Fig. 4f) (Prihatmoko *et al*., 2010).

Hydrothermal alteration

The wallrocks (metamorphic rocks) are strongly weathered, so it is very rare to observe good outcrops in the area. Trenching program by the company along the spurs of Wumbubangka metamorphic mountain range has opened up the soil cover, and exposed clearly the presence of quartz veins and hydrothermally altered rocks. In general, the wallrocks are weakly altered. Strong alteration zone is only restricted surrounding quartz veins (like halos/selvage). The hydrothermal alteration types recognized in the field includes silicification, clay-sericite±-silica (argillic), carbonate alteration and carbonization. Silicification is represented by silicified metasediment and mica schist, whereas clay-sericite±silica (argillic) is mostly present surrounding quartz veins or along structural zones. Prihatmoko *et al*. (2010) also reported the presence of narrow clay-sericite alteration halo (tens cm to 1 m) around the quartz veins in the Roko-Roko hill. Carbonate alteration is typified by the presence of calcite veinlets/stringers, while carbonization is represented by rare occurrences of graphite/carbon with common black color in the quartz vein/adjacent to the altered wall rocks. The carbonization is considered to be one of the alteration type characteristics, associated with orogenic/ metamorphic-hosted gold deposit.

Ore minerals and chemistry

Megascopically it is observed that the quartz veins/reefs/veinlets contain very small amount of sulphide minerals (up to 5 %). Pyrite, chalcopyrite, cinnabar (HgS), stibnite (Sb2S3), tripuhyite (FeSbO4) and rare arsenopyrite (FeAsS2) are present in the quartz veins and silicified metamorphic wallrocks.

Cinnabar is typically pinkish red in color and present abundantly in both primary mineralization and in placer gold deposit. In the placer deposit, the abundance of cinnabar tends to be positively correlated to the presence of gold grains. On the other hand, in the primary mineralization, cinnabar commonly occurred in the form of mineralized layers along foliations of the metamorphic rocks (Fig. 5a).

Stibnite and tripuhyite seem to be filling fractures parallel to foliations (Fig. 5b) and disseminated within the silicified wall rocks. In general, gold is very fine-grain, but occasionally native gold is visible in quartz veins (Fig. 5c,d).

Cinnabar and stibnite are genetically closely related to gold mineralization. Those sulfides could be pathfinder minerals for the exploration of the metamorphic-hosted gold deposit. Bulk-ore

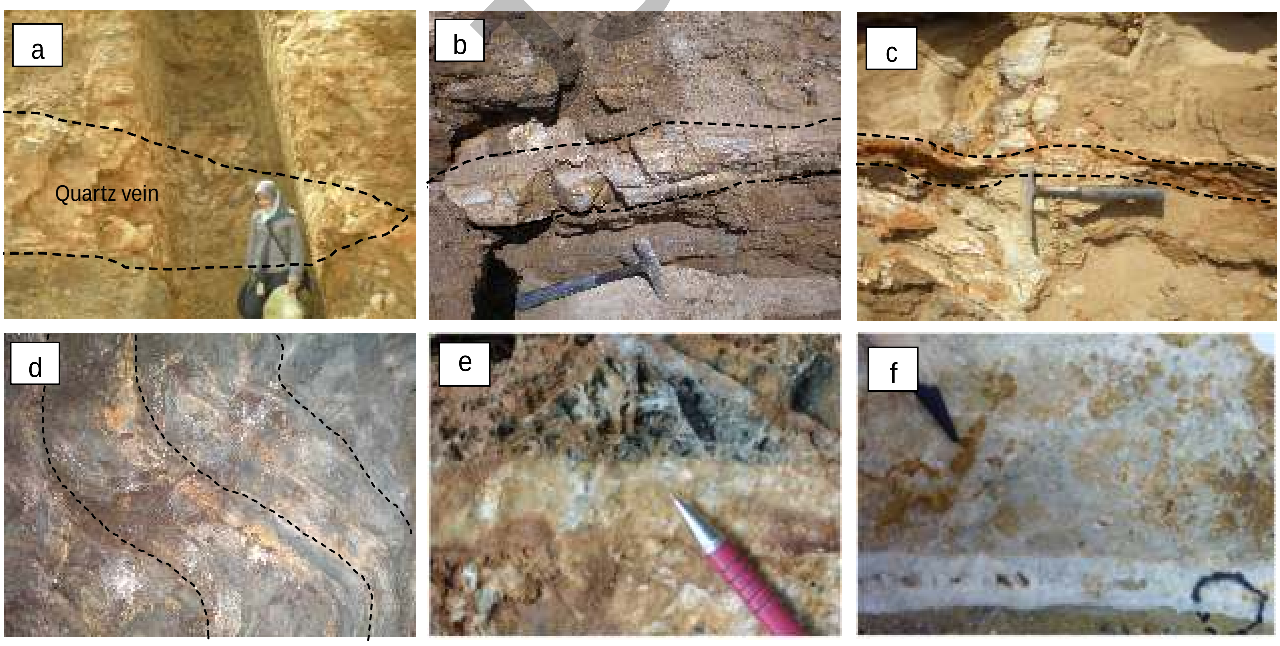

Figure 4. Gold-bearing orogenic quartz vein characteristics: (a). Brecciated/deformed quartz vein (first generation) which is paralel to the foliation of the mica schist (N 300ºE/60º), (b) massive, crystalline quartz vein (first generation) paralel to the foliation, (c) highly oxidized/mineralized deformed second quartz vein cross cutting foliation, (d) A cluster of deformed laminated quartz veins hosted by metasediment, (e). Quartz vein cross-cutting foliation with bladed carbonate at the HW of the vein (upper side), and (f). Multiphase quartz veins cross-cutting foliation in Roko-Roko (visible gold within the black cicle).

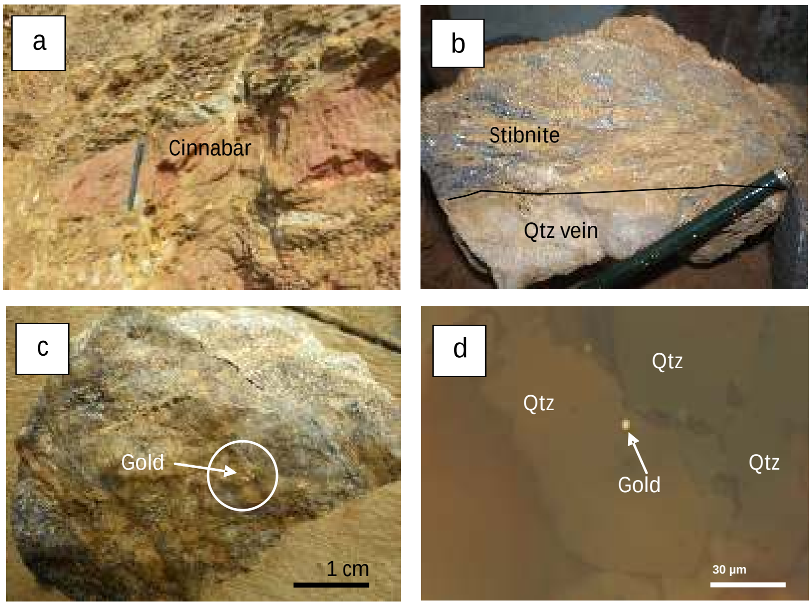

Figure 5. Diagnostic sulfides associated with Bombana orogenic gold mineralization: (a). Layer-like pinkish cinnabar paralel to mica schist foliation, (b). Fibrous stibnite mainly parallel to the foliations, (c). Visible native gold in multiple quartz veins, and (d). Fotomicrograph of free gold in quartz vein.

chemistry analyzed by AAS (Atomic Absorption Spectrometry) indicates a very broad and erratic variation of gold grade ranging from below detection limit (0.005 g/t) to 84 g/t Au (based on present study and Prihatmoko *et al*. (2010)), even a single analysis of quartz vein sample (BVAL-01) from the Valentino cave (a natural cave) in Wumbubangka at the northern part of the Rumbia mountain shows a high Au grade of 134 g/t (Table 2).

Few of the typical pathfinder minerals associated with orogenic/metamorphic-hosted gold deposit are stibnite and tripuhyite. The chemical composition of the minerals analyzed using EPMA (Electron Probe Micro Analyzer) is shown in Table 3, that indicate that both antimony-bearing minerals (stibnite and tripuhyite) contain a significant amount of As of up to 1 wt.%.

Mineralizing fluid characteristics

A total of 6 quartz veins/reefs from three different generations were prepared for fluid inclusion analysis. Microthermometric study with regard to the temperature of melting (Tm) and temperature of homogenization (Th) of fluid inclusions was analyzed by LINKAM THMS600 freezing and heating stage. This study has enabled to understand the characteristics including temperature, salinity and composition of mineralizing hydrothermal fluids that formed the three generations of quartz veins (Table 4).

The data show that Tm of fluid inclusions hosted by first generation of quartz veins (that are parallel to the foliation) tend to be lower ranging from -2.3 to -10 ºC (mean -3.2 to -5.9 ºC) corresponding to relatively higher salinity ranging from 5.26 to 9.08 wt.% NaCl eq.) in comparison to those of other generations of quartz veins/reefs. The temperature of homogenization (Th), interpreted to be the formation temperature of the first generation of quartz vein varies from 184.7 to 245.3 ºC, that are relatively higher than those of other two generations of quartz veins/reefs.

The second generation of quartz veins, that cross-cut foliation and have generally higher gold content, is formed in moderate temperatures of 132.1-283.4 ºC (mean 157.8-208.7 ºC) and salinity of 3.55-5.86 wt.% NCl eq. The latest generation stage of veining represented by quartz+calcite laminated veins was originated at the lowest temperature of 114-176 ºC and salinity of 0.35-4.03 wt.% NaCl eq.

Figure 6 displays the plotting between Th and salinity of fluid inclusions from all quartz vein generations. It is clearly indicatived that the first quartz vein generation underwent "an isothermal mixing with

Table 2. Bulk-ore chemistry of metamorphic-hosted gold quartz veins/reefs from Bombana (in g/t unit).

Sample Codes	Elements (g/t)							
	Au	Cu	Pb	Zn	Ag	Hg	As	Sb
WB-01-B	0.02	13	34	27	<1	1.59	85	198
WB-02-C1	2.52	23	8	10	<1	0.11	212	76
WB-02-C2	1.06	11	16	11	<1	2.79	177	2030
WB-03	0.94	10	<4	30	<1	0.11	428	212
WB-04	1.31	33	11	47	<1	0.30	727	231
WB-06-A	0.10	9	5	3	<1	0.05	23	7
WB-11-A	0.04	12	5	101	<1	1.58	241	417
WB-11-B	<0.005	<2	6	18	<1	0.10	<1	<1
BVAL-01	134	na	na	na	na	na	na	na

Note: na = not analysed

Table 3. Representative chemical data of stibnite and tripuhyite associated with orogenic/metamorphic-hosted gold deposit at Bombana (in wt.% unit).

Analysis no.	Stibnite (Sb_2S_3)				Tripuhyite ($FeSbO_4$)			
	1	2	3	4	5	6	7	8
As	0.24	0.24	0.20	0.24	1.13	1.17	0.79	1.11
S	28.29	28.07	28.40	28.43	0.03	0.04	0.05	0.02
Hg	<0.01	<0.01	<0.01	0.03	0.05	0.01	0.09	0.02
Cu	0.02	0.02	0.01	0.02	<0.01	0.01	0.01	<0.01
Sb	71.87	71.59	71.14	71.42	6.71	6.17	4.07	6.45
Fe	<0.01	<0.01	0.01	<0.01	52.26	52.36	53.03	52.41
Total	100.42	99.92	99.76	100.13	60.17	59.75	58.05	60.02

fluids with contrasting salinity", and is interpreted that the first quartz generation is dominantly originated from hydrothermal magmatic fluid mixing with metamorphic fluids. During the mixing, the temperature change is minor or relatively isothermal, but the salinity decreases significantly. The second and third quartz vein generations are likely formed from mixing of the magmatic and metamorphic fluids, and with cooler less saline meteoric water. This is shown by a systematic decrease of temperature and salinity (Fig. 6).

The evidences of the contribution of metamorphic fluid, hydrothermal magmatic fluids and meteoric water that formed the quartz veins are represented by H2O-NaCl-CO2 fluid inclusions (Fig. 7a,b,c,d). However, petrographically the carbonic fluid inclusions are rarely observed and may contain very small portion of CO2, probably max. 4% CO2 (personal communication, Richard J. Goldfarb, 2011).

Discussion

Based on the key characteristics discussed above, it is interpreted that the secondary (placer) gold in Langkowala, Bombana is likely derived from "orogenic gold", a hydrothermal deposit type for describing sheared gold-bearing quartz veins, which are hosted by metamorphic rocks particularly green schist (cf. Groves *et al.*, 1998).

Table 4. Summary of microthermometric fluid inclusion data from three defferent generations of quartz veins (N = number of data).

Samples	Qtz vein generation	N	Tm °C (mean)	Th °C (mean)	Tm °C (range)	Th °C (range)	Salinity (mean) (wt.% NaCl eq.)
WB - 06 -B	first	37	- 5.9	216.2	- 2.8 - - 10.0	184.7 - 270.0	9.08
WB - 08	first	8	- 3.2	227.5	- 2.3 - - 4.0	201.6 - 245.3	5.26
WB - 01 - A	second	20	- 2.1	201.0	- 1.3 - - 2.7	190.1 - 215.0	3.55
WB - 02 - C	second	33	- 2.4	157.8	- 0.7 - - 3.4	132.1 - 283.4	4.03
WB - 02 - B	second	66	- 3.6	208.7	- 1.9 - - 5.1	190.5 - 231.4	5.86
WB - 11 - C	second (Qtz)	12	- 2.4	186.1	- 1.6 - - 3.5	173.4 - 200.1	4.03
WB - 11 - C	third (Cal)	15	- 1.1	138.2	- 0.2 - - 2.4	114.0 - 176.0	1.91

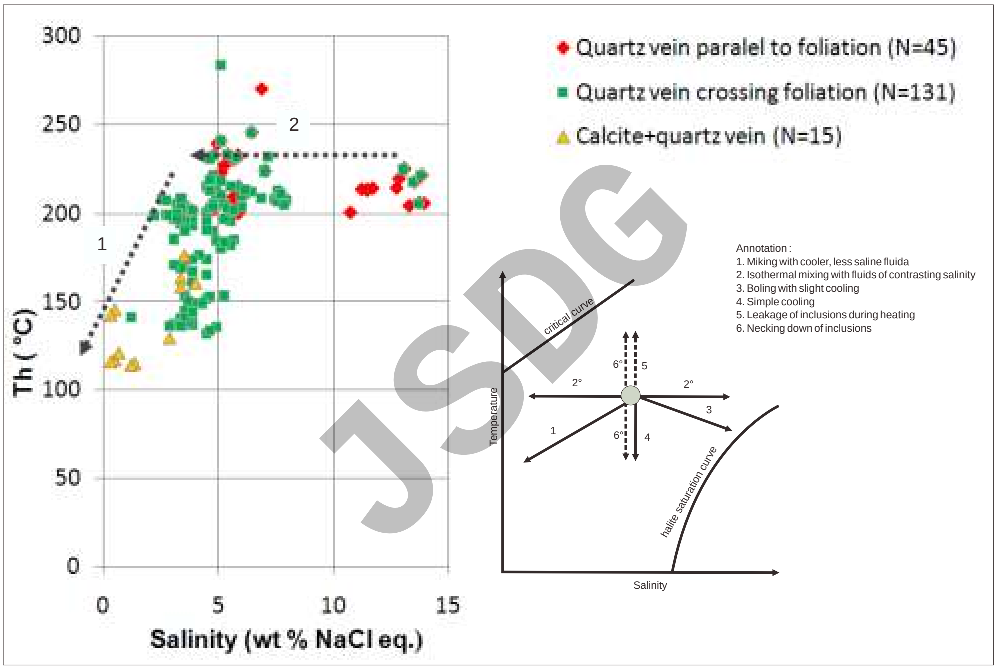

Figure 6. Temperature of homogenization (Th) vs salinity of fluid inclusions from three different quartz vein generations at Bombana metamorphic-hosted gold deposit. The hydrothermal fluid evolution of the three types of quartz veins are also shown and discussed in the text. Schematic model of fluid evolution is adapted from Shepherd *et al*. (1985).

The primary gold mineralization is discovered in Wumbubangka area, at the northern flank of the Rumbia mountain range. From the petrology study it is concluded that the host rock is categorized into greenschist facies. This type of metamorphic facies mostly hosts the orogenic gold deposits worldwide, e.g. Mt. Charlotte, Lancefield and Golden Mile (Gebre-Mariam *et al*., 1995).

The presence of pathfinder minerals such as cinnabar, stibnite and tripuhyite genetically indicates that the orogenic gold deposit in the studied area is emplaced into transition between epizonal and mesozonal referred to the conceptual model of orogenic gold deposit (cf. Groves *et al*., 1998, 2003) (Fig. 8). It implies that the mineralization may be formed at approximately 5 km depth below paleosurface. In addition, the observable characteristics of gold-bearing quartz veins/veinlets have met with the criteria of orogenic gold type, i.e.

sheared/deformed, segmented, brecciated and occasionally sigmoidal, which are the key indications for brittle condition of the epizonal-mesozonal transition. The typical characteristics of the quartz veins are also recognized in Hutti metamorphic-hosted gold mineralization, Dharwar Craton, India. Seven generations of sigmoidal and laminated quartz veins are identified (Rogers, 2004).

The quartz veins/reefs are commonly characterized by massive and crystalline textures. However, druzy and pseudomorph bladed carbonate textures are also occasionally recognized (Prihatmoko *et al*., 2010). Although it is uncommon, but bladed carbonate could be present in orogenic quartz veins/reefs if the hydrothermal fluids forming the deposit have the right phase separation situation (personal communication, Richard J. Goldfarb, 2011).

CO2-rich fluid inclusion is present in very small portion, but it is occasionally recognized particularly in the quartz veins/reefs of first generation. It seems that CO2 content is relatively low in the fluid inclusions. Alternatively, the scarcity of CO2 contents in the fluid inclusions could be explained as follows. According to the conceptual orogenic deposit model from Groves *et al*. (1998, 2003), the Bombana gold-bearing quartz vein is situated at shallow level, in which the pressure condition may not be sufficient to preserve CO2 in the hydrothermal fluids and it may escape up to the surface (personal communication, Volker Lueders, 2003). The similar features of the metamorphic-hosted gold deposits are also recognized in the Milparinka-Tibooburra district, NW-New South Wales, Australia. The gold-bearing quartz veins are hosted by low-grade metamorphic rock and deformed sedimentary rocks. Two generations of quartz veins are identified and their formation is characterized by CO2-rich mineralizing fluids (Thalhammer, 2000).

Conclusions

The paleoplacer/placer (secondary) gold grains hosted by Langkowala formation in Bombana, SE-Sulawesi are evidently derived from massive, crystalline, partly brecciated, sigmoidal, sheared and segmented, laminated gold-bearing quartz ± calcite veins/reefs with thickness from 2 cm to 2 m hosted by Pompangeo Metamorphic Complex (PMC). The PMC particularly consists of mica schist (dominant rock type), phyllite and metasediment (commonly metasandstone and marble) occupying the Rumbia Mountain range. Mica schist is abundantly composed of muscovite, chlorite and quartz with a small amount of actinolite, albite, epidote, sericite and opaque minerals. Hence, the metamorphic rock is categorized into green schist facies, which is noted as an important host rock facies for orogenic gold deposit worldwide. The metamorphic rocks are strongly weathered, however trenching program has has opened up the soil cover and exposes the hydrothermal alteration zones. In general, the wallrocks are weakly altered. Strong alteration zone is only restricted surrounding quartz veins (like halos/selvage). The hydrothermal alteration types recognized includes silicification, clay-sericite ± silica (argillic alteration), carbonate alteration and carbonization. Silicification is represented by silicified metasediment and mica schist, whereas clay-sericite ± silica (argillic) is mostly present surrounding quartz veins or along structural zones.

At least three generations of the metamorphic rock-hosted quartz veins are identified. The first is parallel to the foliations, the second crosscuts the first generation of veins/foliations, and the third is of laminated deformed quartz + calcite veins at the late stage. Gold grades in the second and third veins are relatively higher than that in first veins. The veins contain erratic gold in various grades from below detection limit (0.005 g/t) to 134 g/t. Mineralogically, gold is genetically related to cinnabar, stibnite, tripuhyite and possibly minor arsenopyrite. Gold is mainly identified in the form of 'free gold' among silicate minerals particularly quartz.

Fluid inclusion study of quartz veins indicates abundant H2O-NaCl and a small amount of H2O-NaCl-CO2 inclusions. Temperature of homogenization (Th) and salinity of the first vein vary from 184.7 to 245.3 ºC and 5.26 to 9.08 wt.% NaCl eq., respectively. The second generation vein was originated at Th of 132.1-283.4 ºC and salinity of 3.55-5.86 wt.%NaCl eq., whereas the third generation vein formed at lowest Th varying from 114 to 176ºC and less saline fluid at salinity range between 0.35 and 4.03 wt.% NaCl eq. The first generation quartz vein underwent “an isothermal mixing with fluids with contrasting salinity”, and is interpreted it is dominantly originated from hydrothermal magmatic fluid mixing with metamorphic fluids. During the mixing, the temperature change is minor or relatively isothermal, but the salinity decreases significantly. The second and third quartz vein generations are likely formed

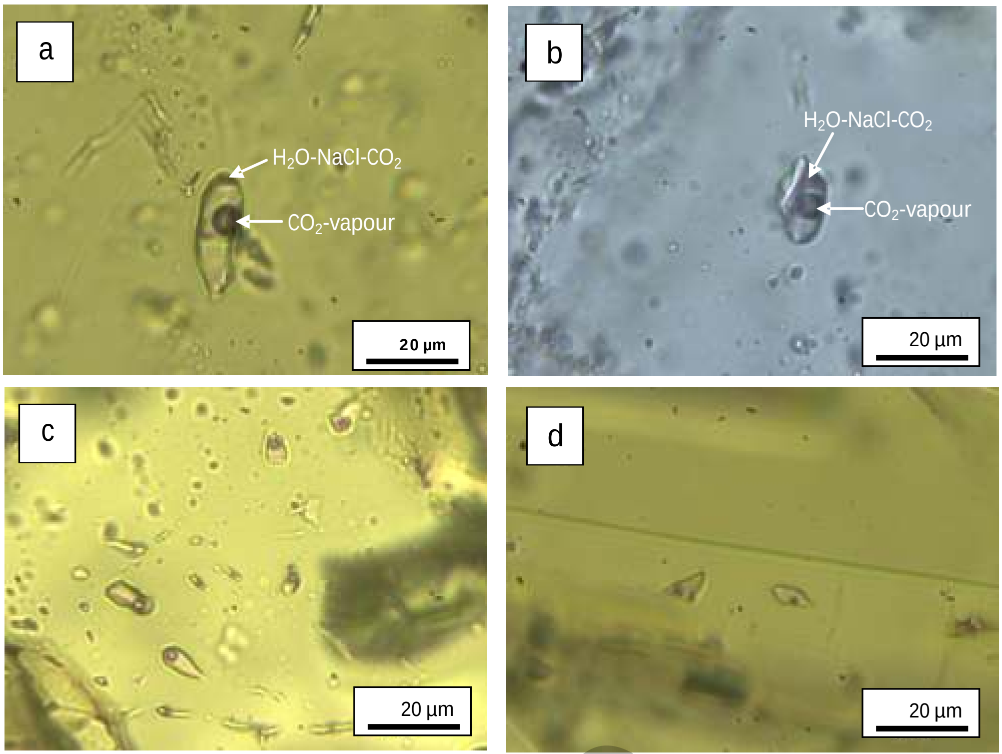

Figure 7. Fluid inclusion study: (a) and (b). CO2-rich L-V fluid inclusions hosted by quartz veins, (c). H2O-NaCl ± (CO2) L-V fluid inclusions in quartz veins, and (d). H2O-NaCl ± (CO2) L-V fluid inclusions hosted by calcite.

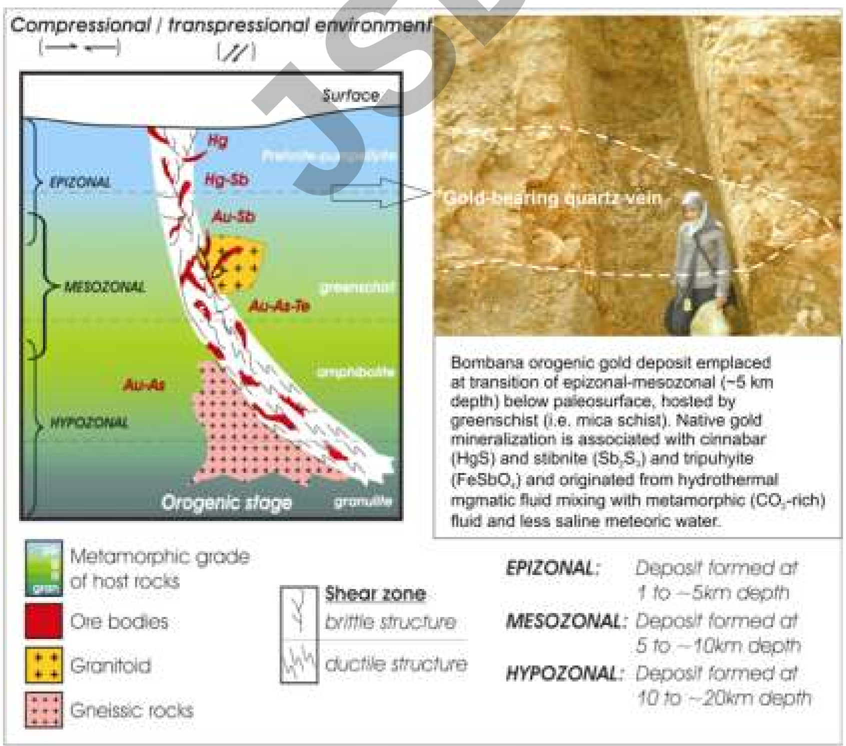

Figure 8. The Bombana metamorphic-hosted gold deposit plotted on the conceptual orogenic gold deposit model from Groves et al. (1998, 2003) emplaced into shallow level at the transition between epizonal and mesozonal (approximately 5 km below paleosurface).

from mixing of the magmatic and metamorphic fluids, and with cooler less saline meteoric water. The evidences of the contribution of metamorphic fluid, hydrothermal magmatic fluids and meteoric water that formed the quartz veins are represented by H2O-NaCl-CO2 fluid inclusions. However, petrographically the carbonic fluid inclusions are rarely observed and may contain very small portion of CO2, probably max. 4% CO2.

It could be summarized that by considering all key features discussed above, although it may partly be still debatable, the primary metamorphic-hosted gold mineralization type at Bombana tends to meet the criteria of 'orogenic gold type' (cf. Groves *et al*., 1998; 2003), rather than epithermal or other hydrothermal deposit types. Therefore, the discovery of the metamorphic-hosted gold deposit in the Rumbia metamorphic mountain range and its vicinity has opened up more targets and challenges for new gold exploration target in the region, and other terrains in Indonesia that have identical geological setting.

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