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# GEOCHEMICAL SIGNATURE OF THE ELANG PORPHYRY Cu-Au DEPOSIT IN SUMBAWA ISLAND, INDONESIA

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**Abstract -** The demand for copper and gold has increased significantly, but finding new exposed porphyry deposits has become more challenging. Elang porphyry Cu-Au deposit is one of few world class deposits, discovered in the last 30 years, located in Sumbawa Island, Indonesia. This study aims to understand the correlation between geochemical elements in porphyry mineralization using soil and core sample data. The research methods include collecting soil and core samples, conducting geochemical analysis, and processing and interpreting the data. The research results show that The Cu-Au mineralization at Elang is mainly within and around multiple tonalite intrusions where intense of early quartz-sulphide and potassic alteration dominates, constrained by the extent of advanced argillic alteration. Tonalite is distinguished based on cross-cutting relationships, texture, and the crystal shape of quartz eye that is present as a phenocryst. The crystalline shapes are closely aligned with the copper and gold mineralization. Variations in the styles of geology and mineralization contribute to differing geochemical expressions of the porphyry deposits. Geochemical data, especially from soil samples, emerges as a valuable method for identifying signatures within porphyry mineralization deposits. The copper, zinc, lead, and molybdenum clearly point to the central of the porphyry system, while broad zones of high gold anomalies are associated with epithermal high-sulfidation systems. Analysis of core samples reveals that the Cu/Au ratio exhibits a distinct vertical zonation pattern throughout the porphyry body. Understanding the geology and geochemical characteristics of the Elang deposit provides valuable insights for exploration strategies aimed at discovering similar deposits elsewhere.

**Key words**: porphyry Cu-Au, geochemical soil anomaly, Elang deposits

***Sari*** *– Permintaan akan tembaga dan emas telah meningkat secara signifikan, namun menemukan deposit porfiri baru yang tersingkap di permukaan merupakan sebuah tantangan. Deposit porfiri Cu-Au Elang adalah salah satu dari sedikit deposit kelas dunia yang ditemukan dalam 30 tahun terakhir, berlokasi di Pulau Sumbawa, Indonesia. Penelitian ini bertujuan untuk memahami korelasi antar unsur geokimia dari mineralisasi porfiri dengan menggunakan data sampel tanah dan sampel bantuan inti. Metode penelitian meliputi pengumpulan sampel tanah dan batuan inti, analisis geokimia, serta pemrosesan dan interpretasi data. Hasil penelitian menunjukkan bahwa mineralisasi Cu-Au di Elang terutama terdapat di dalam dan sekitar intrusi tonalit yang beragam, didominasi oleh alterasi kuarsa-sulfida awal dan potasik yang intens, dengan mineralisasi terbatas pada alterasi argilik lanjut. Intrusi tonalit dibedakan berdasarkan hubungan potong-memotong, tekstur, dan bentuk kristal mata kuarsa yang hadir sebagai fenokris. Bentuk kristal ini berkaitan erat dengan mineralisasi tembaga dan emas. Variasi geologi dan mineralisasi berkontribusi pada ekspresi geokimia yang berbeda dari deposit porfiri. Studi geokimia, terutama dari sampel tanah, merupakan metode yang berharga untuk mengidentifikasi tanda-tanda mineralisasi porfiri. Anomali tembaga, seng, timbal, dan molibdenum dengan jelas menunjukkan pusat sistem porfiri, sementara zona luas anomali emas tinggi dikaitkan dengan sistem epitermal sulfidasi tinggi. Analisis sampel inti mengungkapkan bahwa rasio Cu/Au menunjukkan pola zonasi vertikal yang berbeda di seluruh tubuh porfiri. Memahami karakteristik geologi dan geokimia deposit Elang memberikan wawasan berharga untuk strategi eksplorasi yang bertujuan menemukan deposit serupa di tempat lain.*

***Kata kunci****: Tembaga-emas porfiri, anomali geokimia tanah, deposit Elang*

## 1. INTRODUCTION

The porphyry deposit are very important sources of copper and gold (Sillitoe, 2010). The demand for copper and gold has increased significantly, but finding new exposed porphyry deposits has become more challenging. The formation of porphyry deposits is a complex process involving the interplay of magmatic, hydrothermal, and structural factors, resulting in the formation of large-tonnage, low-grade copper-gold mineralization (Cooke et al., 2014).

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The Elang porphyry Copper (Cu) – Gold (Au) deposit is located in Sumbawa Island, Indonesia, approximately 60 km West of the Batu Hijau porphyry copper/gold active mine (Figure 1). This deposit is part of the Sunda-Banda arc, a highly prospective region for porphyry and epithermal mineralization systems (Garwin, 2002; Maryono et al., 2018). The Sunda-Banda arc is a result of the northward subduction of the Indo-Australian plate beneath the Eurasian plate, which has led to the development of numerous volcanic and intrusive complexes along the arc (Hamilton, 1979).

**Figure 1**. Elang porphyry deposit location.

Mineralization at Elang was first identified by Newmont geologists in 1988 following a regional geochemical program conducted in 1987-1988, which defined anomalous gold and copper, with Elang being the top-ranking anomaly. Initially, drilling efforts focused on the epithermal gold potential of the area. However, the discovery of porphyry-style mineralization at Batu Hijau in late 1990 prompted a revaluation of the Elang data within a porphyry copper context. An intensive exploration program in 1990 and a drilling program in mid-1991 led to the discovery of porphyry Cu-Au mineralization at Elang. Subsequent drilling programs in 2003 resulted in the discovery of early-stage intrusion and higher copper grades (Bastian et al., 2015).

Since 1990, efforts have been made to establish community support, field camps, drilling activities, baseline environmental and social studies, as well as Mineral Resource estimates. Drilling programs occurred in 1988, 1994-1995, 1998, 2003-2006, and 2011-2023. However, a comprehensive understanding of the deposit's geological and geochemical characteristics is crucial for effective exploration targeting, resource estimation, and mine planning.

This study aims to understand the geology and mineralization of the Elang porphyry Cu-Au deposit through the integration of geochemical soil data. Geochemical soil surveys are widely used in mineral exploration as they can delineate geochemical anomalies associated with buried mineralization (Piercey, 2011). The findings of this study will contribute to the knowledge of porphyry copper-gold systems in the Sunda-Banda arc and potentially guide for future exploration and development strategies in the region.

## 2. DEPOSIT GEOLOGY

The deposit area predominantly covered by an old andesitic volcanic unit, with multiple intrusion complexes along a NNE trending corridor, including diorite, intrusive breccia, various tonalites (Charlie, Delta, Echo), dacite porphyry, and diatreme breccia (Bastian et al., 2015), Figure 2.

The Cu-Au mineralization at Elang is mainly within and around multiple tonalite intrusions where intense early quartz-sulphide and potassic alteration dominates, constrained by the extent of advanced argillic alteration. Tonalite varieties are distinguished based on cross-cutting relationships, texture, and the crystal shape of quartz eyes present as phenocrysts (Lubis et al., 2005). The Charlie tonalite has anhedral quartz eyes, Delta tonalite has subhedral quartz eyes, and Echo tonalite has euhedral quartz eyes (Figure 3). These crystal shapes are closely associated with copper and gold mineralization. The main porphyry intrusions are Charlie and Delta tonalites, while Echo tonalite is the late intrusion that disrupts the copper mineralization.

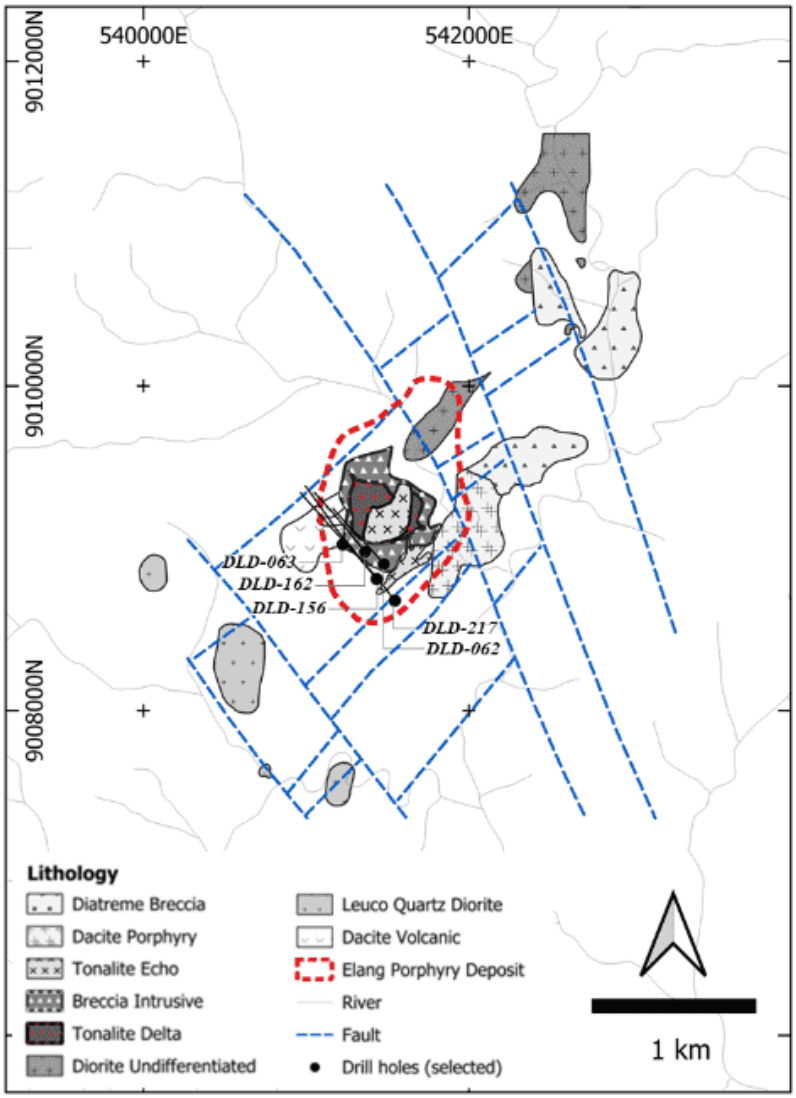


**Figure 2.** Elang geological map (Bastian et al., 2025).

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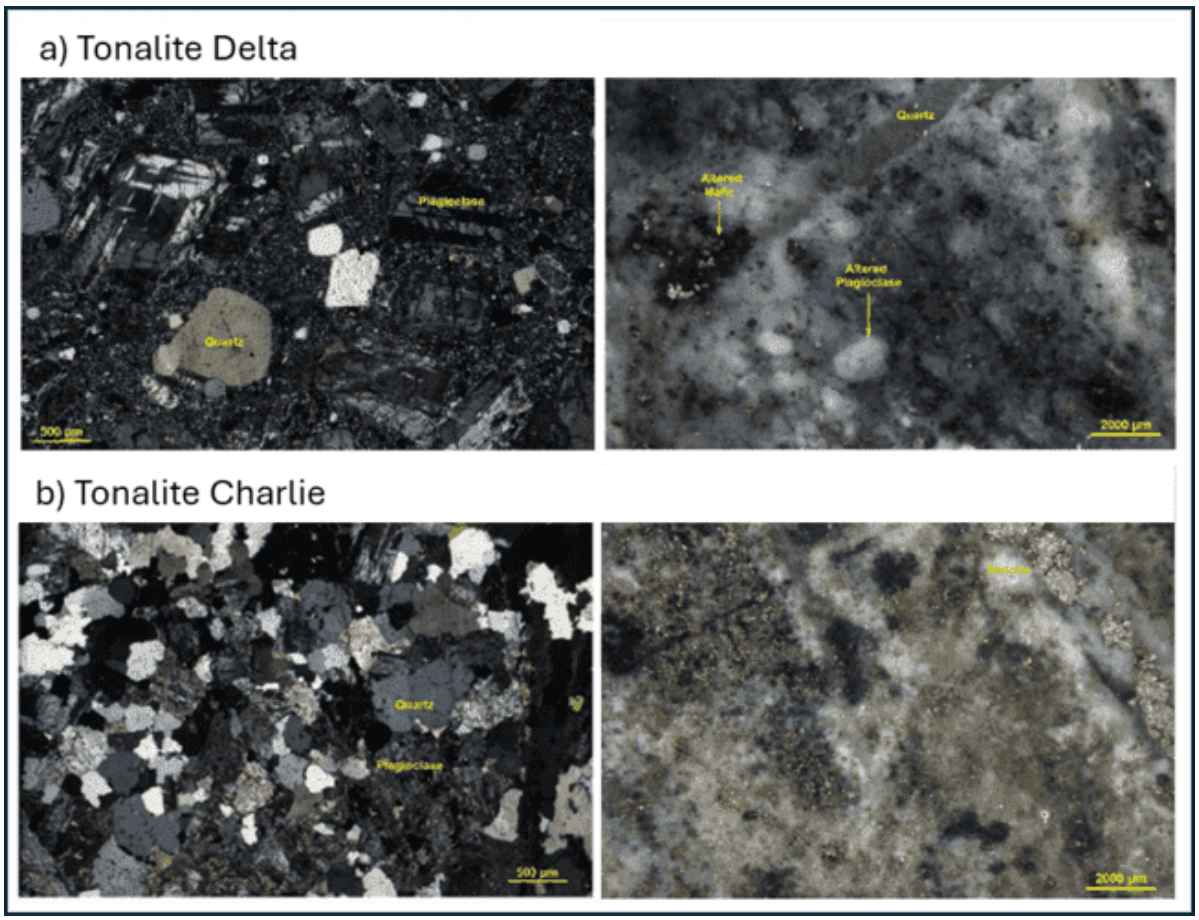


**Figure 3**. Transmitted light, cross-polars photomicrographs (left) and megascopic pictures (right) of a). Delta tonalite from hole DLD-062 at 580.3m depth; b0. Charlie tonalite from hole DLD-062 at 829.8m depth (Bastian et al., 2015).

## 3. DATA AND RESEARCH METHODS

### 3.1. Sample Collection and Preparation

Soil geochemical sampling was carried out across the Elang prospect area to delineate geochemical anomalies associated with the porphyry Cu-Au mineralization. A grid-based soil sampling approach was employed, with samples collected at regular intervals along traverses oriented perpendicular to the interpreted strike of the mineralized system.

Soil samples were taken within an area of 1,200 Ha that is divided into 50 - 200m grid cells, which covers the Elang deposit, typically at a depth of 20-30 cm below the surface, using a hand auger or shovel. The minimum weight of each sample is 500 g. Each sample placed in a kraft sample bag labeled with a unique sample ID. The sample locations were recorded using a handheld GPS unit with sub-meter accuracy. In the field camp, the soil samples were air-dried and sieved to obtain the -80 mesh (<0.18 mm) fraction. This fraction was then pulverized to a fine powder using a ring mill or a ceramic pulverizer to ensure homogeneity and representativeness of the sample. Totally 2,478 composite samples were taken and submitted to the laboratory for analysis Cu, Au, molybdenum (Mo), lead (Pb), and zinc (Zn).

Five cored holes (4,779.40m) were selected within the primary Elang porphyry mineralization zone to examine the geochemical signature across the depth profile of the deposits (DLD-062, DLD-063, DLD156, DLD-162, and DLD-217) .

### 3.2. Analytical Methods

In exploration geochemistry, analytical methods aim to focus on the geochemical aspects of samples that indicate mineralization. Therefore, a crucial

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part of designing an exploration geochemical program is choosing the right analytical method (Cohen and Bowell, 2013). The pulverized soil samples were analyzed for a suite of elements, including Cu, Au, Mo, Pb, and Zn. Au is determined using graphite furnace-atomic absorption spectroscopy (GF-AAS), whereas Cu, Mo, Pb, and Zn were determined using inductively coupled plasma-mass spectrometry (ICP-MS) – shown in Table 1.

Similar to soil analysis, the drillcore samples were analyzed for five elements: Cu, Au, Mo, Pb, and Zn (Table 2). Au was determined using graphite furnace-atomic absorption spectroscopy (GF-AAS). Cu was analyzed using two methods: triple acid digestion (3-Acid) for drillholes DLD-062 and DLD-063, and inductively coupled plasma-mass spectrometry (ICP-MS) for drillholes DLD-156, DLD-162, and DLD-217. The other elements (Mo, Pb, and Zn) were determined using inductively coupled plasma-mass spectrometry (ICP-MS).

**Table 1.** The analytical techniques and its detection limits for soil samples.

| Element | Analytical method | Detection limit | |
|---|---|---|---|
| Au | GF-AAS | 1 | ppb |
| Cu | ICP - MS | 5 | ppm |
| Pb | | 2 | ppm |
| Zn | | 2 | ppm |
| Mo | | 1 | ppm |

**Table 2.** The analytical techniques and its detection limits for core samples.

| Element | Analytical method | Detection limit | |
|---|---|---|---|
| Au | GF-AAS | 1 | ppb |
| Cu | 3 Acid digest | 0.01 | % |
| Pb | 3 Acid digest | 0.01 | % |
| | ICP – MS | 2 | ppm |
| Zn | 3 Acid digest | 0.01 | % |
| | ICP-MS | 2 | ppm |
| Mo | ICP-MS | 1 | ppm |

### 3.3. Data Processing and Interpretation

The geochemical data were processed using Leapfrog software for exploratory data analysis ("EDA"). EDA is conducted to determine the correlation between Cu, Au, Pb, Zn, and Mo. The correlation matrix is determined using the Spearman approach. The classification of correlation coefficients according to Schober et al. (2018) follows a conventional approach (Table 3).

**Table 3**. Conventional approach to Interpreting a correlation coefficient (Schober et al.)

| Correlation Coefficient | Interpretation |
|---|---|
| 0,00 - 0,10 | Negligible correlation |
| 0,10 - 0,39 | Weak correlation |
| 0,40 - 0,69 | Moderate correlation |
| 0,70 - 0,89 | Strong correlation |
| 0,90 - 1,00 | Very strong correlation |

The spatial distribution of each element was generated using contouring tools in QGIS software, while simple graphs were employed to visualize the signature of each element by depth. This geochemical data provided a valuable dataset for understanding the geochemical signature and footprint of the Elang porphyry Cu-Au deposit.

## 4. RESULTS

The soil geochemical survey conducted over the Elang porphyry Cu-Au deposit area revealed distinct geochemical patterns and anomalies that provide valuable insights into the mineralization system. The Spearman correlation for the soil samples is presented in Table 4 below.

**Table 4**. Spearman corelation for soil geochemical data.

| Elements | Au ppb | Cu ppm | Mo ppm | Pb ppm | Zn ppm |
|---|---|---|---|---|---|
| Au_ppb | **1.00** | 0.30 | 0.26 | -0.02 | -0.15 |
| Cu_ppm | 0.30 | **1.00** | 0.43 | -0.10 | -0.16 |
| Mo_ppm | 0.26 | 0.43 | **1.00** | -0.56 | -0.65 |
| Pb_ppm | -0.02 | -0.10 | -0.56 | **1.00** | 0.87 |
| Zn_ppm | -0.15 | -0.16 | -0.65 | 0.87 | **1.00** |

In general, the Spearman correlation results show that Cu has a weak correlation with Au, Pb, and Zn, and a moderate correlation with Mo.

### 4.1. Copper and molybdenum anomalies

The highest Cu and Mo values were observed in the central part of the surveyed area, coinciding with the interpreted location of the Elang deposit (Figure 4 and 5). This zone is characterized by a well-defined, concentric Cu-Mo anomaly, with values reaching up to 3,700 ppm Cu and 381 ppm Mo. The spatial distribution and association of these two elements are consistent with the typical geochemical signature of porphyry Cu-Au deposits, where Cu and Mo are considered primary pathfinder elements (Sillitoe, 2010).

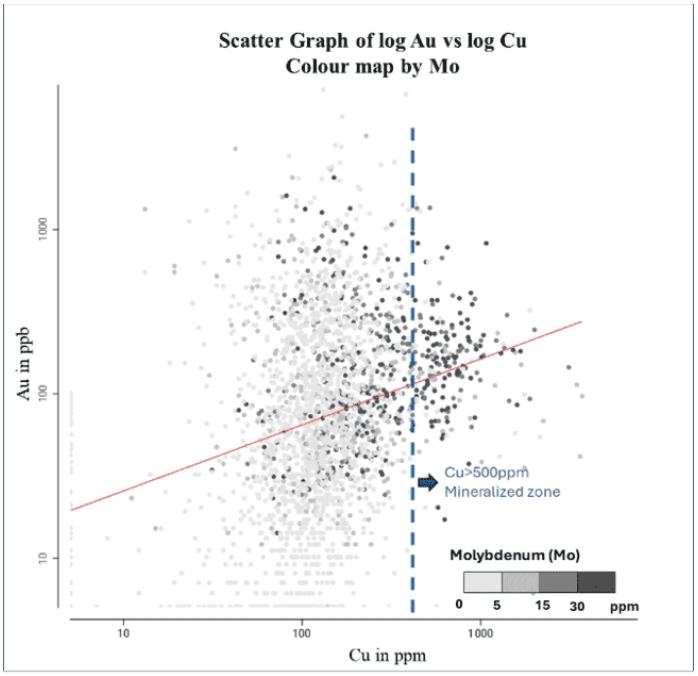


**Figure 4.** Scatter plot of Cu vs Au, with Mo as the color parameter.

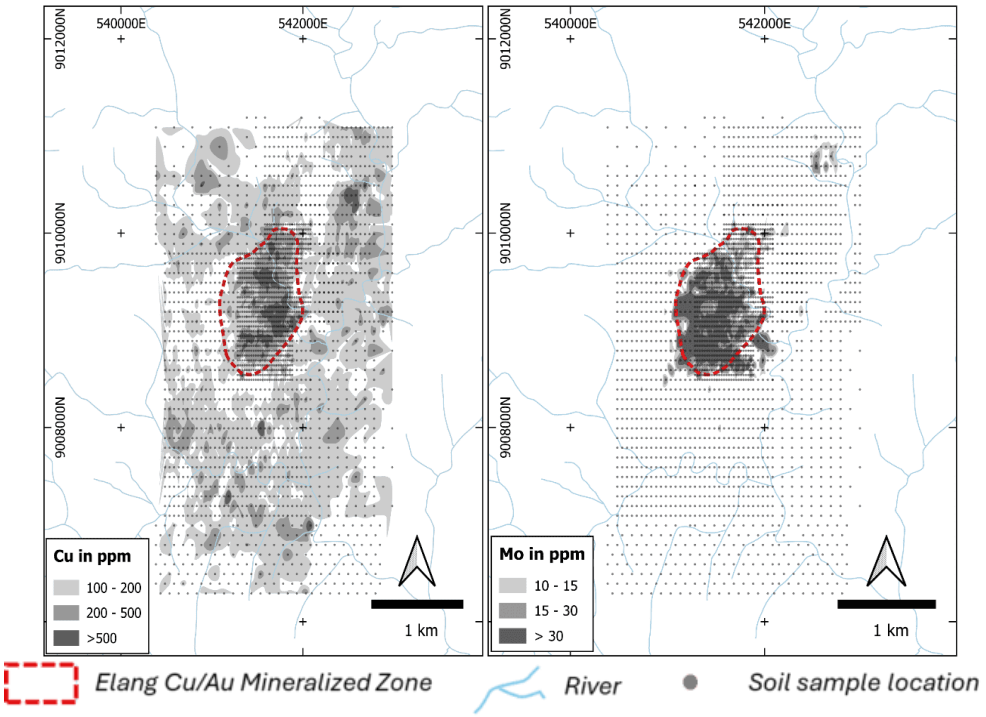


**Figure 5.** Geochemistry soil anomalies – copper and molybdenum anomalies.

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### 4.2. Zinc and Lead Depletion Zone

An intriguing feature observed in the geochemical data is the presence of a distinct Zn and Pb depletion zone that encompasses the central Cu-Mo anomaly (Figure 7). This low-Zn zone is characterized by Zn values generally below 20 ppm, contrasting with the elevated Zn values (>500 ppm) observed in the peripheral areas (Figure 6). While the low-Pb zone is generally below 20 ppm, concentrating with elevated Pb values above 100 ppm (Figure 8).

This depletion pattern is consistent with the formation of a lithocap or leached cap, a common feature in porphyry systems, where Zn and Pb are depleted due to intense hydrothermal alteration and leaching processes (Sillitoe, 2010; Cooke et al., 2014).

### 4.3. Gold Anomalies

While the Cu-Mo anomaly delineates the potential porphyry core, the distribution of Au anomalies exhibits a different pattern. High Au values (up to 7,100 ppb) are predominantly observed in the southern and eastern parts of the surveyed area (Figure 9). These Au anomalies are spatially offset from the central Cu-Mo anomaly, suggesting a potential overprint or superposition of an epithermal high-sulfidation (HS) mineralization event. Epithermal HS systems are often associated with Au enrichment and can occur as a later overprinting event on porphyry deposits (Sillitoe, 2010; Cooke et al., 2014).

Two epithermal high-sulfidation systems, Ladam and Sebu, situated to the southeast of the Elang deposit, are responsible for the Pb, Zn, and Au anomalies.

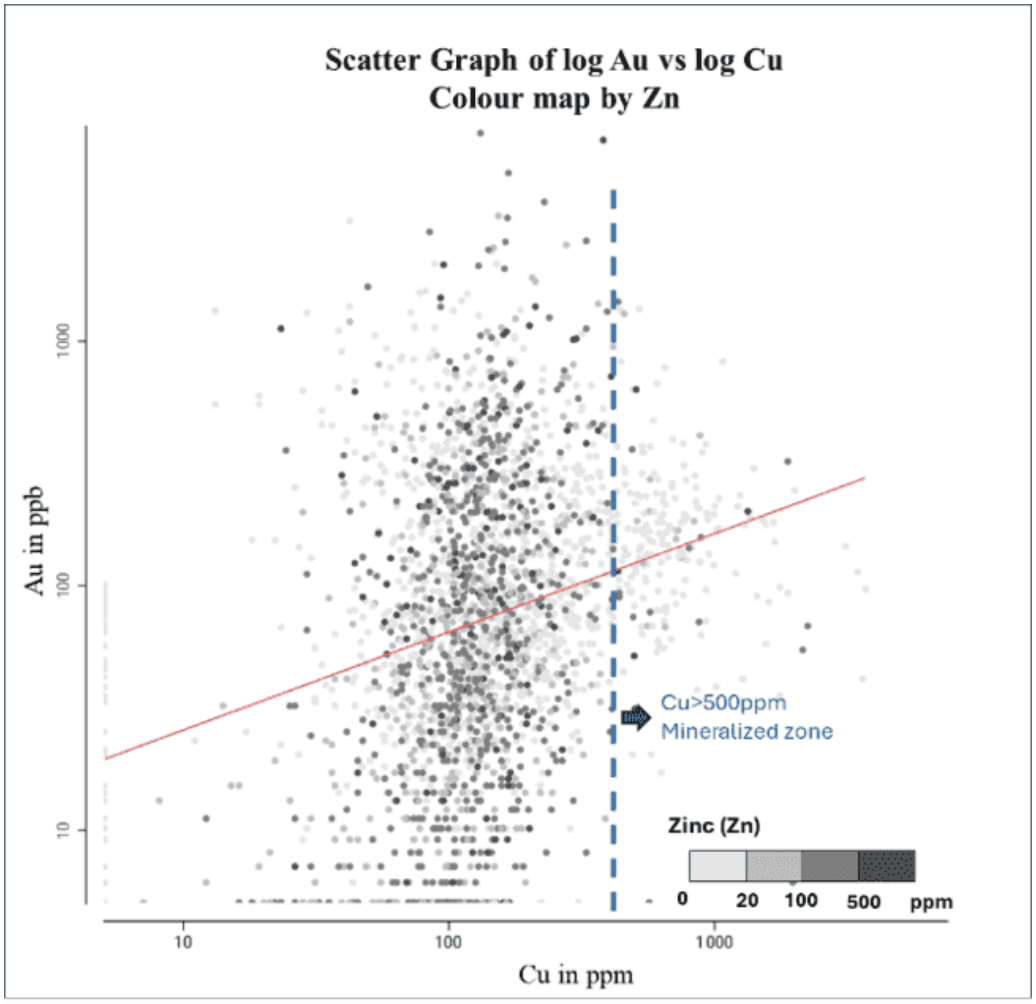


**Figure 6.** Scatter plot of Cu vs Au, with Zn as the color parameter.

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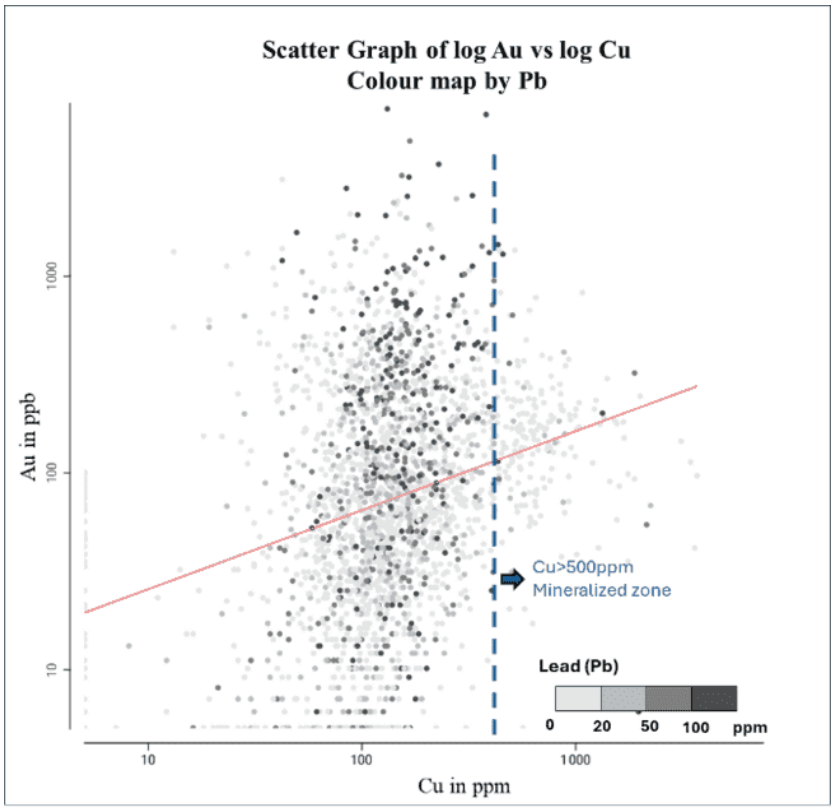


**Figure 7.** Scatter plot of Cu vs Au, with Pb as the color parameter.

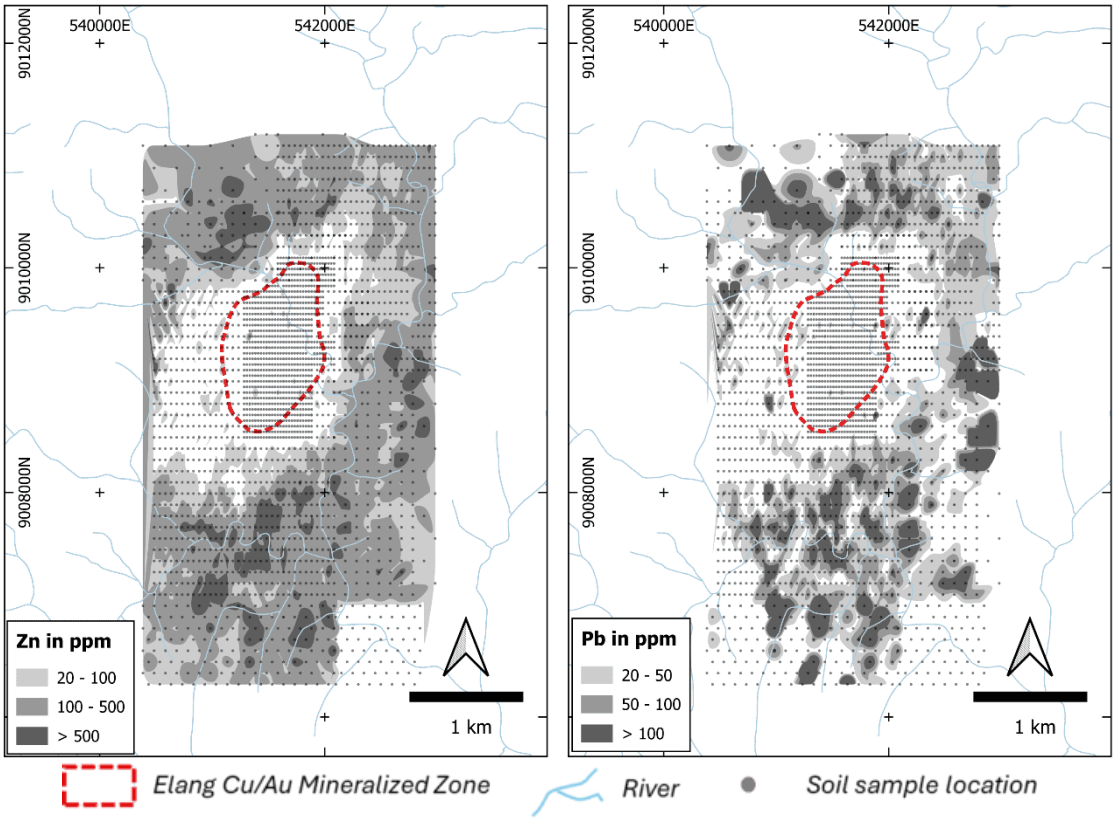


**Figure 8.** Geochemistry soil anomalies – zinc and lead anomalies.

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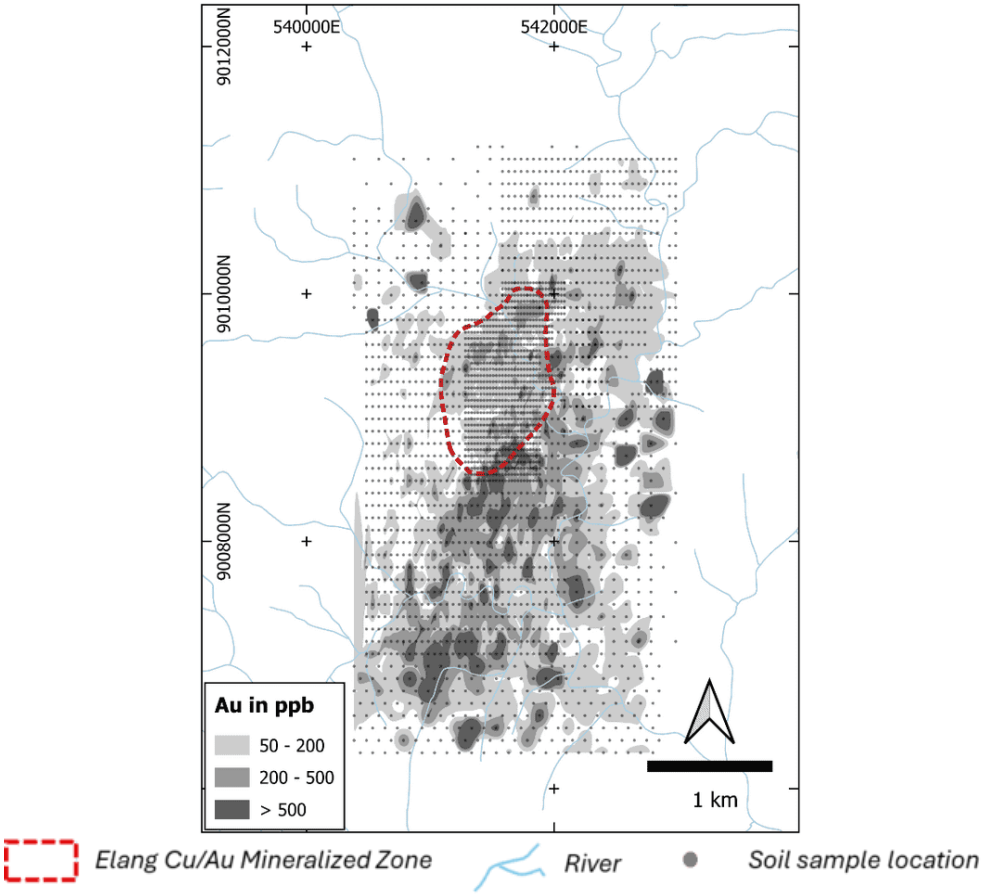


**Figure 9.** Geochemistry soil anomalies – gold anomalies.

### 4.4. Geochemical signature by depth

The results of a vertical geochemical profile study of the Elang porphyry deposit are presented in Figure 10. The Cu distribution tends to be homogeneous from the surface to depth. In contrast, gold concentration shows an increase below 0 mRL (mean >0.5 ppm Au) and subsequently decreases below -250 mRL (mean <0.3 ppm Au). Pb and Zn do not exhibit strong anomalies. Meanwhile, Mo content appears to decrease with depth but increases again at -250 mRL, coinciding with the zone of gold grade reduction.

This interpretation is further supported by a similar trend observed in the Cu/Au ratio with depth. The ratio pattern from the upper to the lower parts of the intrusive body shows a progression from Cu>Au to Cu=Au, then Cu<Au, before returning to a Cu>Au zone at greater depths.

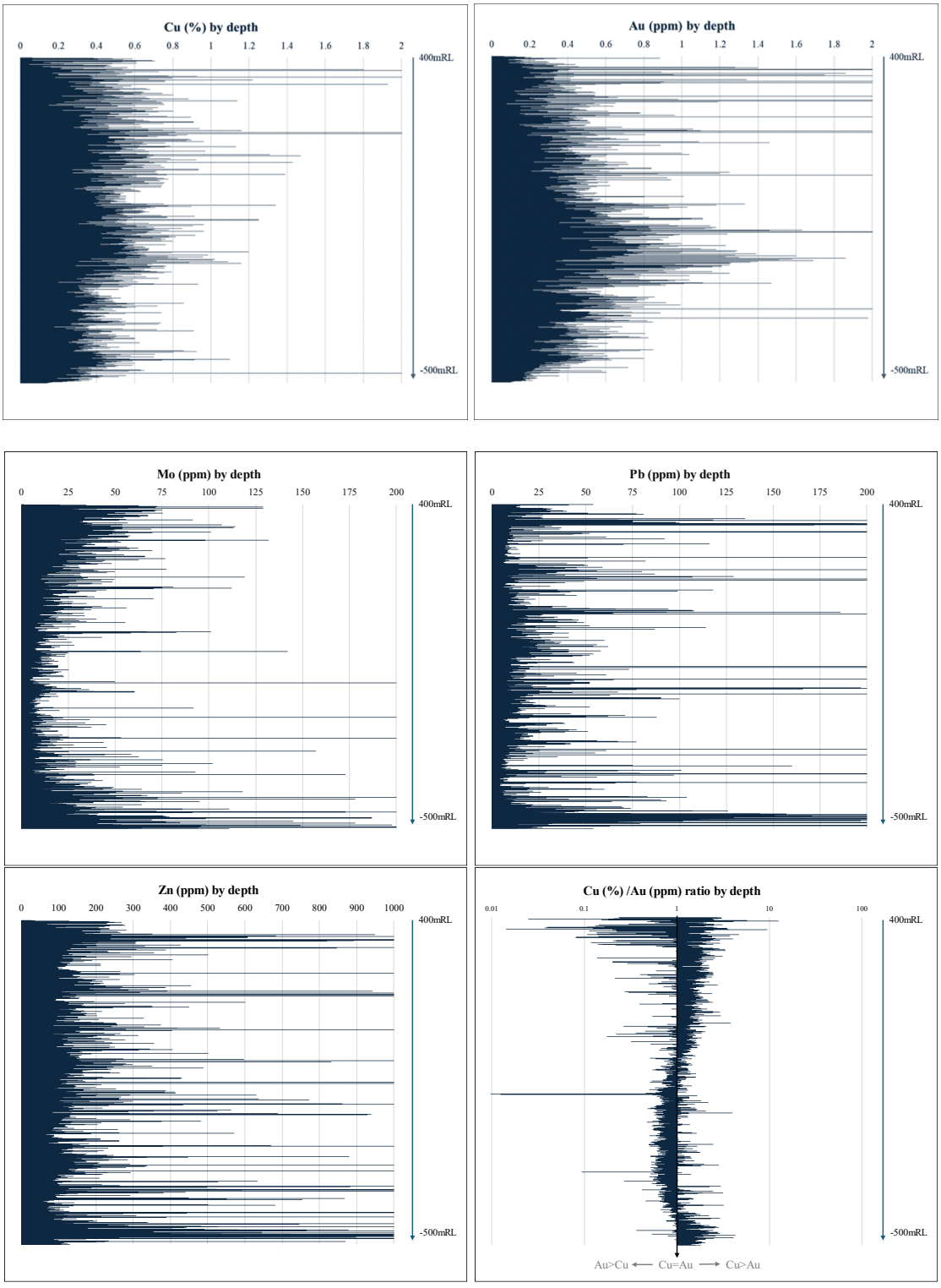


**Figure 10.** Vertical geochemical signatures of Elang porphyry body.

## 5. DISCUSSION

The geochemical anomalies in Elang deposits suggest a classic porphyry system. These deposits typically feature a central zone rich in Cu and sometimes Mo and Au. Around this core, there are usually zones with higher levels of Zn, Pb, Ag, and sometimes Mn (Halley, 2015).

Cu/Au ratio can vary significantly from one deposit

to another. The relationship between the Cu/Au ratio and depth in porphyry deposits is mainly influenced by changes in the total gold grade. The origin of the primary magma may contribute to the metal content in regional and individual deposits, but it doesn't fully explain the general relationship between metal ratios and ore formation pressure (Murakami et al., 2010). The Cu/Au ratio in porphyry systems is a key aspect in understanding the mineralization process and economic potential of these deposits. While numerous studies have focused on analyzing the global Cu/Au ratio in various porphyry deposits, there is a growing interest in investigating how this ratio varies with depth within individual systems.

Based on this study, the low Cu/Au ratio in deeper level of Elang deposit aligns with the high intensity of quartz stockwork zone with high copper sulphide content (Chalcopyrite and bornite) within the volcanic rock, which remains open to the south. That's indicate the other deeper porphyry intrusion. This is consistent with the presence of a deeper satellite porphyry intrusion to the south, known as the Elang South porphyry (Figure 11).

By analyzing the patterns of Cu/Au ratio variation with depth, researchers can gain deeper insights into mineralization processes and refine exploration and mining strategies in porphyry systems. This research enhances our scientific understanding of ore deposit formation and has practical implications for the mineral exploration and mining industry.

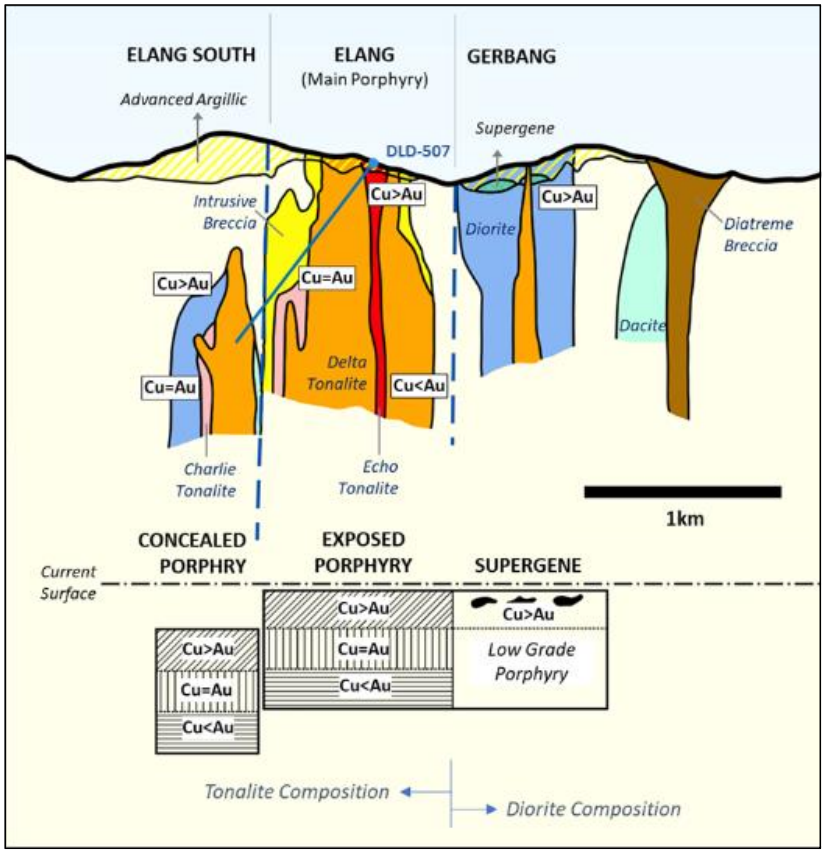


**Figure 10.** Elang porphyry deposits conceptual model – Cu/Au ratio approach

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## 6. CONCLUSIONS

The geochemical data suggest that the Elang deposit exhibits a classic zonal pattern of porphyry system, with a well-defined high zone of Cu and Mo anomalies, and low Zn and Pb anomalies. While a peripheral zone of elevated Au values is related to a superimposed epithermal LS/HS event.

The geochemical study of the Elang porphyry

deposit reveals distinct vertical zonation patterns for copper, gold, and molybdenum. While copper distribution remains relatively homogeneous, gold shows peak concentrations between 0 mRL and -250 mRL, and molybdenum displays an inverse relationship with gold. The Cu/Au ratio exhibits a systematic variation with depth, transitioning from Cu>Au to Cu<Au before returning to Cu>Au at greater depths. This Cu>Au zone at depth suggests another deeper mineralized porphyry intrusion. This pattern aligns with the mineralization zone and has led to the successful discovery of the Elang South porphyry intrusion.

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## REFERENCES

Bastian, A., Kepli, S., Sulistyo, H., and Hendri, D., 2015, Exploration Significance of Elang Porphyry Cu-Au Deposit, Sumbawa-Indonesia: NNT presentation to the MGEI 7th Annual Convention – Balikpapan, October 4-5th 2015,.

Cohen, D., and Bowell, R., 2013, Exploration Geochemistry: Treatise on Geochemistry: Second Edition, v. 13, p. 623–650, doi:10.1016/B978-0-08-095975-7.01127-X.

Cooke, D.R., Hollings, P., Wilkinson, J., and Tosdal, M., 2014, Geochemistry of Porphyry Deposits, *in* Treatise on Geochemistry, Oxford: Elsevier, v. 13.

Garwin, S., 2002, The Geologic Setting of Intrusion-Related Hydrothermal Systems near the Batu Hijau Porphyry Copper-Gold Deposit, Sumbawa, Indonesia, *in* Goldfarb, R.J. and Nielsen, R.L. eds., Integrated Methods for Discovery: Global Exploration in the Twenty-First Century, Society of Economic Geologists, v. 9, p. 0, doi:10.5382/SP.09.15.

Halley, S., 2015, Footprints: Hydrothermal Alteration and Geochemical Dispersion Around Porphyry Copper Deposits: Society of Economic Geologists Newsletter, v. 100, p. 1–17.

Hamilton, W.B., 1979, Tectonics of the Indonesian region: Professional Paper Report 1078, doi:10.3133/pp1078.

Lubis, H., Maryono, A., Perdanakusumah, A., and Hermawan, W., 2005, The Elang Porphyry Copper and GoldMineralization Style Sumbawa, Indonesia: Indonesian Minerals and Coal Discoveries, IAGI,.

Maryono, A., Rachel L, H., R Cooke, D., Rompo, I., and Hoschke, T.G., 2018, Tectonics and Geology of Porphyry Cu-Au Deposits along the Eastern Sunda Magmatic Arc, Indonesia: Economic Geology, v. V. 113, p. 7–38.

Murakami, H., Seo, J.H., and Heinrich, C.A., 2010, The relation between Cu/Au ratio and formation depth of porphyry-style Cu–Au ± Mo deposits: Mineralium Deposita, v. 45, p. 11–21, doi:10.1007/s00126-009-0255-1.

Schober, P., Boer, C., and Schwarte, L.A. Correlation Coefficients: Appropriate Use and Interpretation: Anesthesia Analgesia, v. 126 (5), p. 1763–1768.

Sillitoe, R.H., 2010, Porphyry Copper Systems*: Economic Geology, v. 105, p. 3–41, doi:10.2113/gsecongeo.105.1.3.