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LOW SULFIDATION EPITHERMAL GOLD DEPOSITS IN INDONESIA: CHARACTERISTICS AND EXPLORATION IMPLICATIONS – AN UPDATE

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Abstract

Indonesia is famous for its abundant occurrences of gold deposits of various mineralization types, i.e. porphyry, low-sulfidation epithermal/ LSE, intermediate-sulfidation epithermal/ ISE, high-sulfidation epithermal/ HSE, volcanogenic massive sulfide/ VMS), orogenic gold, etc. The total gold endowment from those types of mineralization accounted to 10,288 tons, of which the LSE (+ISE) type contributed to total of 1,251 tons or 12.2% of the gold endowment. This significant credit of LSE (+ISE) gold to the amount of gold endowment represents the importance of LSE gold mineralization type as an exploration target. Hence this study aims to provide a comprehensive overview of LSE in Indonesia today and its implications for future exploration initiatives. A total of 85 gold deposits/ occurrences, that has been reported and/ or considered as LSE types have been selected for the assessment and evaluation in this study. Several parameters have been used to assess each occurrence. Further exploration programs that have resulted in recent discoveries or re-definition of LSE gold deposits in general have been vectored based on the comprehensive assessment of the targets. The improved understanding of Indonesian LSE deposits particularly on the tectonic and geological setting, controlling structures, mineralized body shapes and metal contents, alteration system and size with regards to the LSE environmental levels would reduce the challenges and hurdles on recognition and identification of the LSE signatures.

Keywords: Low sulfidation epithermal, LSE, mineral exploration

Introduction

In Indonesia gold production and apparently the exploration works related to it had begun since the 19th century during the Dutch era (Van Bemmellen, 1949). Some of the old gold deposits and prospects that have been reported, e.g. Cikotok in western Java (Banten), Mangani in West Sumatera, Lebong Tandai and Lebong Donok in Bengkulu, Paleleh in north arm Sulawesi (Van Bemmelen, 1949; Marcoux & Milesi, 1994; Kavalieris et al, 1987; Van Leeuwen, 2018), even until to date are still the objects of exploration and/ or mine-redevelopment. On the other side, new gold deposits and prospects have been discovered and/ or redefined after the Indonesian independence (1945), particularly during the modern mining (and exploration) era since early 70's or after the implementation of mining law No. 11/1967. They have been more contributing to the numbers of gold production and endowment in Indonesia.

These gold deposits and occurrences individually have in general been studied technically and been reported for their genetic mineralization types by the project owners and researchers of government institutions and universities, and some of them have been published. They were reported to be originated in association with mineralization types of porphyry, low-sulfidation epithermal/ LSE, intermediate-sulfidation epithermal/ ISE, high-sulfidation epithermal/ HSE, volcanogenic massive sulfide/ VMS), orogenic gold, etc. The total gold endowment from those various types of mineralization accounted to 10,288 tons (Figure 1). For comparison, Badan Geologi (Geological Agency) of Indonesia reported the total gold inventories (resource + reserve) of 15,472 tons (Badan Geologi, 2024).

Methods

A total of 85 gold deposits/ occurrences, that has been reported and/ or considered as LSE types have been selected for the assessment and evaluation in this study. The parameters assessed at each deposits/ occurrences include: (1) tectonic setting and major structure that may relate to the deposit/ occurrence, (2) magmatic arc association, (3) general geology (particularly its association with host rock type and intrusive relationship/ influence), (4) mineralization characteristics (type, shape, textures, geochemical/ pathfinder element association, Au-Ag ratio, salinity from fluid inclusion data if any, and presence or absence of silica sinter in the system), (5) Alteration footprint (type and distribution/ coverage area), (6) Age of the deposit/ occurrence and/ or its host rock, (7) Size of the deposits/ occurrences (resource and reserve) if any, and (8) historical timing of the discovery or re-definition of the deposits/ occurrences. As a note, the age of the mineralization (or alteration) used is of the radiometric dating data in some of the deposits/ prospects. For those that do not have radiometric dating data, comparison to the relative age of their host rocks have been applied.

This assessment could be used to direct/ vector to interpretation of mineralization zone level/ position in the paleo-hydrothermal system that form the deposit/ occurrence.

Results and Discussion

Based on this study, it is noted that the LSE (+ISE) gold type has contributed to total of 1,251 tons or 12.2% of the gold endowment of Indonesia. (Figure 1). This significant credit of LSE (+ISE) gold to the amount of Indonesian gold endowment represents the importance of LSE gold mineralization type as an exploration target, hence this study aims to provide a comprehensive overview of LSE in Indonesia today and its implications for future exploration initiatives.

The mineral exploration boom triggered by the implementation of Mining Law No.11/ 1967 has resulted in increasing the number of LSE gold discoveries, i.e. 21 in the period of 1981-1990 and 39 in 1991-2000. After 2000, the discoveries drastically turned down, even during the last 24 years (2001-2024) only 10 discoveries could be made (Figure 2). It could likely be due to the economic and political crisis in Indonesia (at the end of 90’s) which was then aggravated by the downturn of exploration and mining industry.

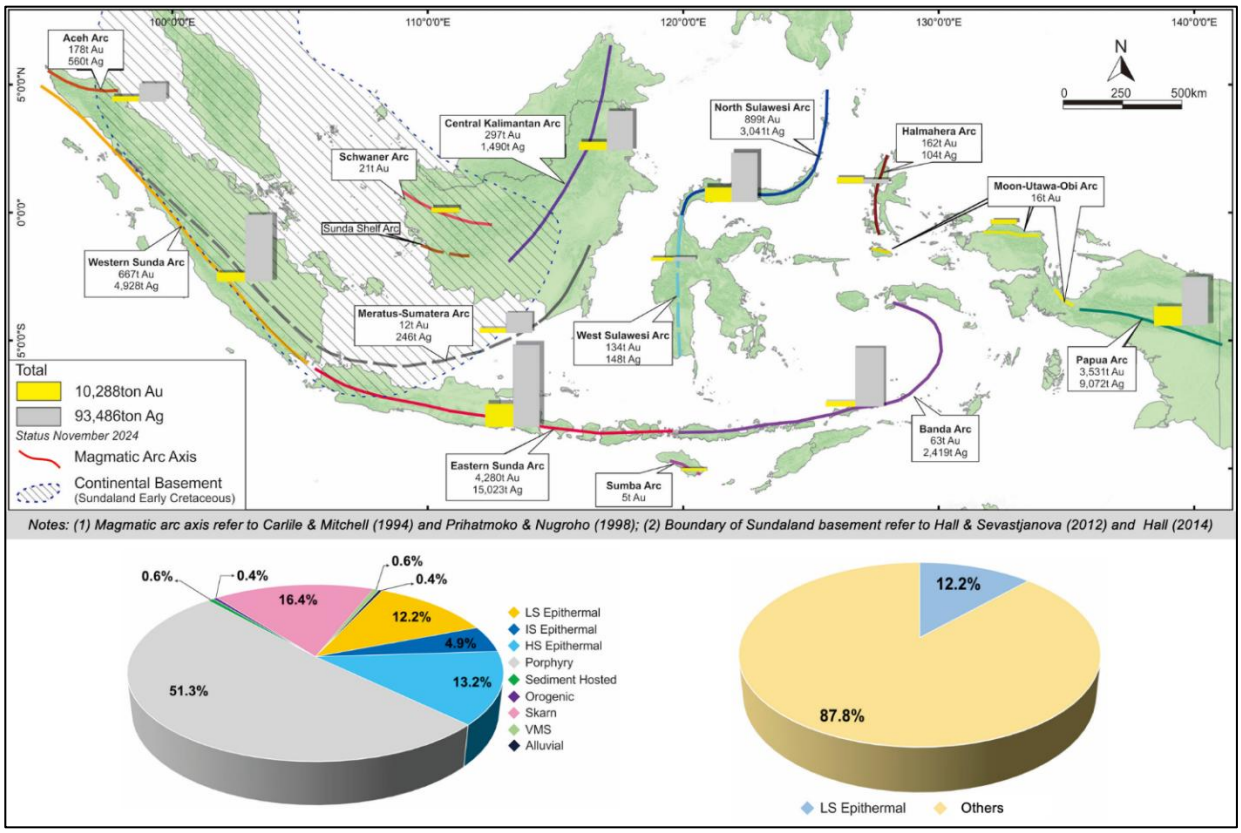


Figure 1. Gold endowment/ inventory of Indonesia (by magmatic arcs and deposit types)

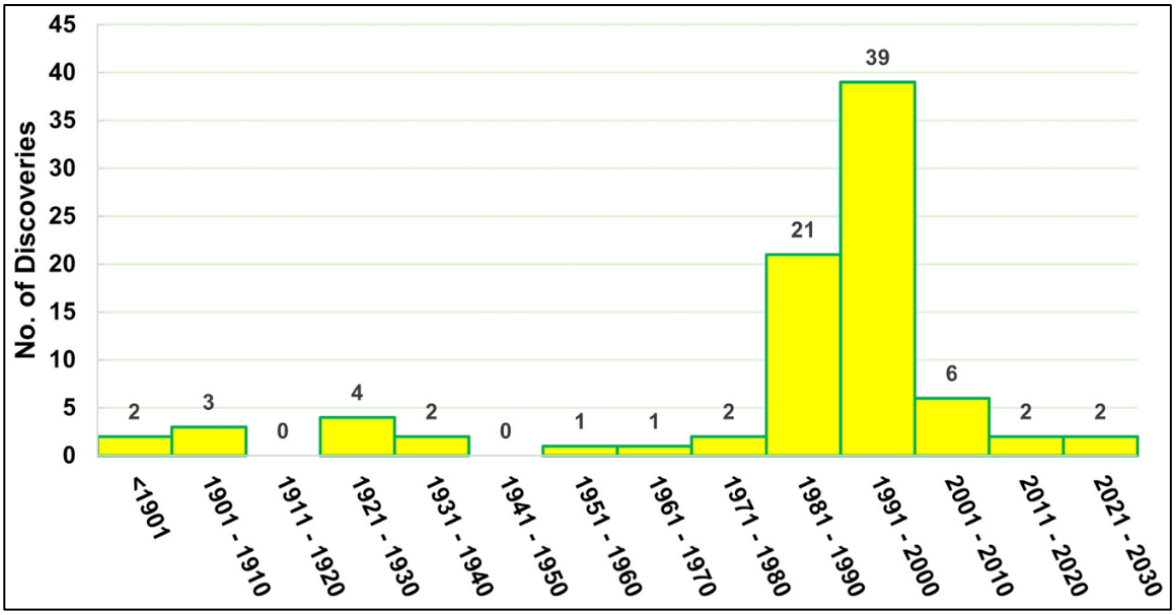


Figure 2. Historical record of the discoveries of LSE gold deposits/ occurrences in Indonesia

Tectonic Setting

The LSE gold deposits and occurrences are located, distributed, and in association with known magmatic arcs (referring to Carlile & Mitchell, 1994; Prihatmoko & Nugroho, 1998; Maryono et al, 2018), including Aceh Arc (1/ 1.2%), Western Sunda (16/ 18.8%), Eastern Sunda (28/ 32.9%), Sumba Arc (1/ 1.2), Central Kalimantan Arc (18/ 21.2%), West Sulawesi Arc (3/ 3.5%), North Sulawesi Arc (9/ 10.6%), Halmahera Arc (8/ 9.4%), and Moon-Utawa-Obi Arc (1/ 1.2%) – (Figure 2). In term of the tectonic setting including the basement types, they could be grouped as having close association with continental arc (based by Early Cretaceous Sundaland terrane): island/ volcanic arc: 30/ 35.3%, continental arc: 49/ 57.6%, back-arc of the volcanic arc: 3/ 3.5%, and other setting, closely to the suture zone: 3/ 3.5% (Figure 3).

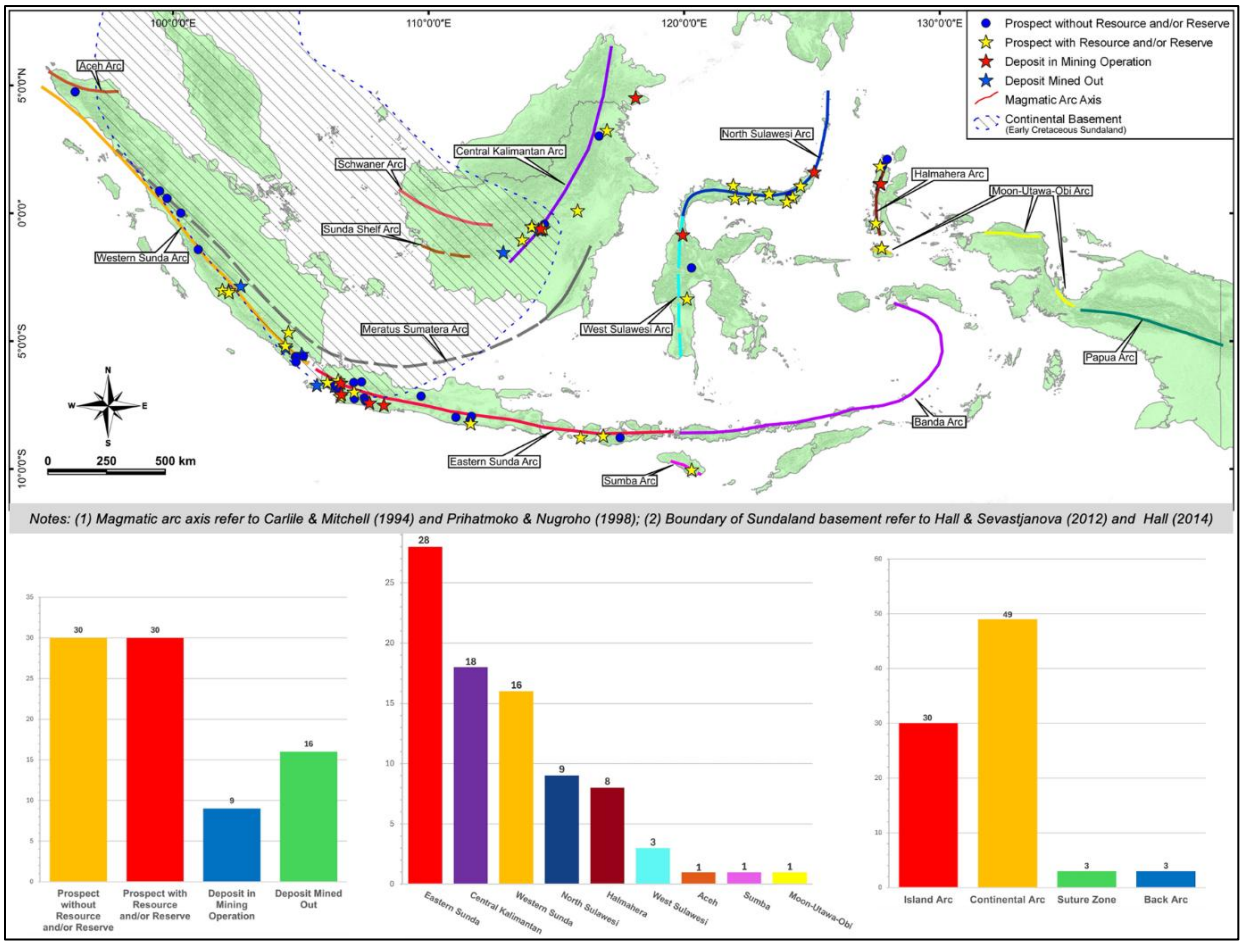


Figure 3. Location of LSE gold deposits and occurrences showing the project status and their spatial relationship with the general tectonic setting and magmatic arcs

Hydrothermal System Affinities

In term of the hydrothermal system affinities (referring to White et al, 1995), of 85 LSE deposits/ occurrences, 8 districts (consisting of 18 deposits/ occurrences) are associated with acidic/ silicic volcanism (typified by rhyolitic, rhyodacitic, and dacitic host rocks or volcanic plugs), while the other 67 deposits/ occurrences are related with andesitic volcanism, typified by andesitic host rocks

and intermediate intrusives (diorite) – (see Figure 4). It is also common that the LSE mineralized systems in silicic volcanism are associated with structural depression (e.g. caldera) such as in Kerta and Pongkor (Lubis et al, 2012; Prihatmoko & Idrus, 2020), and Totopo (Santos et al, 1999; Budiman et al, 2011). The caldera system in silicic volcanism also commonly produced large volume of pyroclastics (e.g. ignimbrite), covering the mineralization system, such as in Kerta and partly Pongkor (Lubis et al, 2012; Prihatmoko & Idrus, 2020). It is interesting that among 18 deposits/ occurrences that are associated with silicic volcanism,14 of them occurred in the continental arc setting (it seems that the basement type might influence this situation). Another point to be given attention is that bimodal volcanism is also very common to be associated with the silicic volcanism that carry LSE gold mineralization e.g. Kerta, Pongkor and Cibaliung (Angeles et al, 2002; Lubis et al, 2012; Prihatmoko & Idrus, 2020).

Sinter Manifestation and Mineralization Age

The presence or absence of sinter in the system has also been assessed, as it could indicate the position level of the LSE system. The presence of sinter would indicate that the system is preserved up to the surface or near surface. It has been noted that 17 (20%) deposits/ occurrences have sinter association, and interestingly 8 of them are associated with silicic volcanism (see Figure 4).

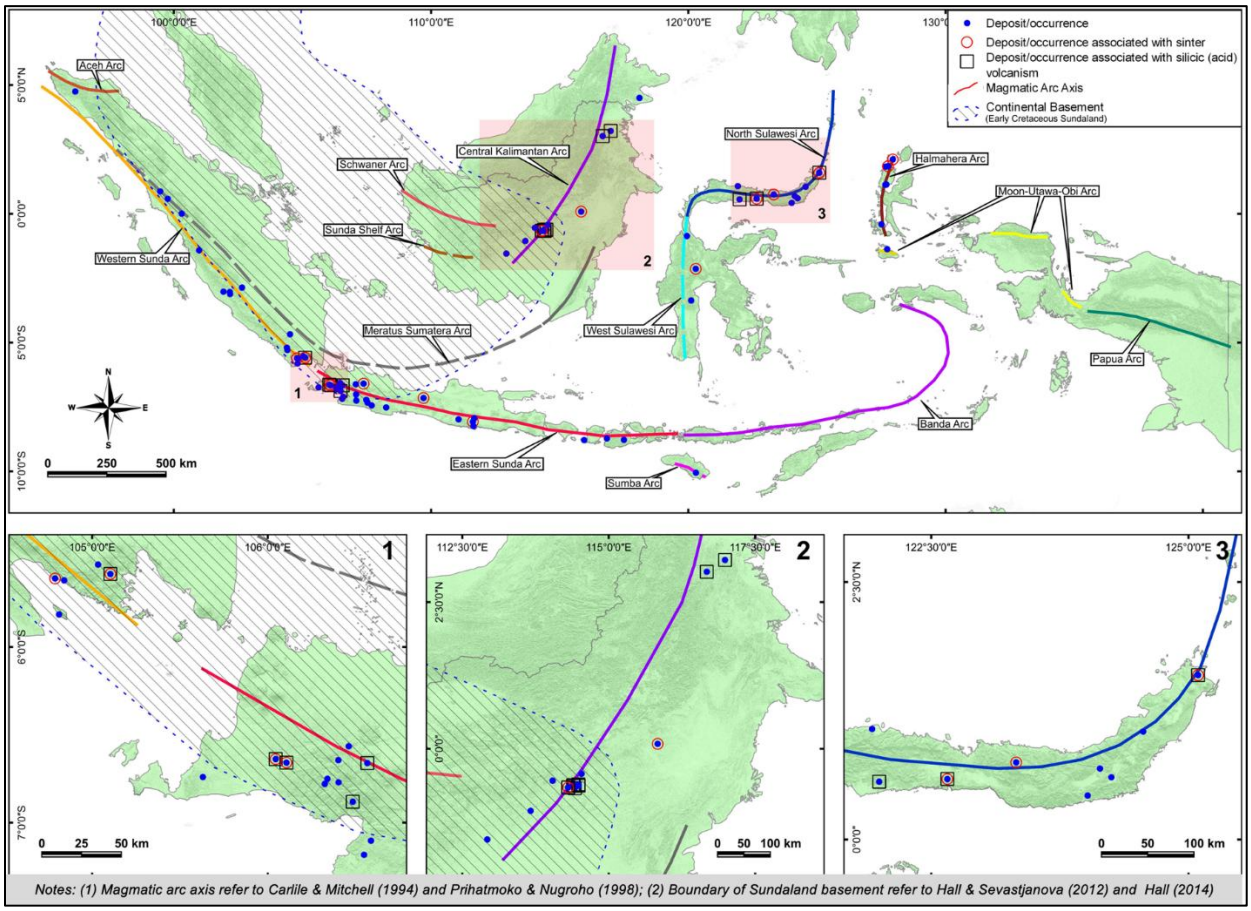


Figure 2. LSE deposit/ occurrence locations informing the associated volcanic-magmatic affinities and sinter presence/ absence in the systems.

Regarding the mineralization age, of 85 deposits/ occurrences, 21 of them have absolute age data (by radiometric dating). Therefore, for the other 64, their ages have been determined by comparing to the relative age of the host rocks (based on the geological map). From this age assessment, it can be noted that in majority (42/ 49.4%) the LSE deposits/ occurrences are of Oligocene age (33.0 – 22.5 Ma), and the second biggest group is of Late Pliocene age (21/ 24.7%), as well as the third group is of Late Miocene age (10/ 11.8%) – (see Figure 5). The presence of 3 major age populations (Late Oligocene/ Oligo-Miocene, Late Miocene, and Late Pliocene) are interesting to be discussed further.

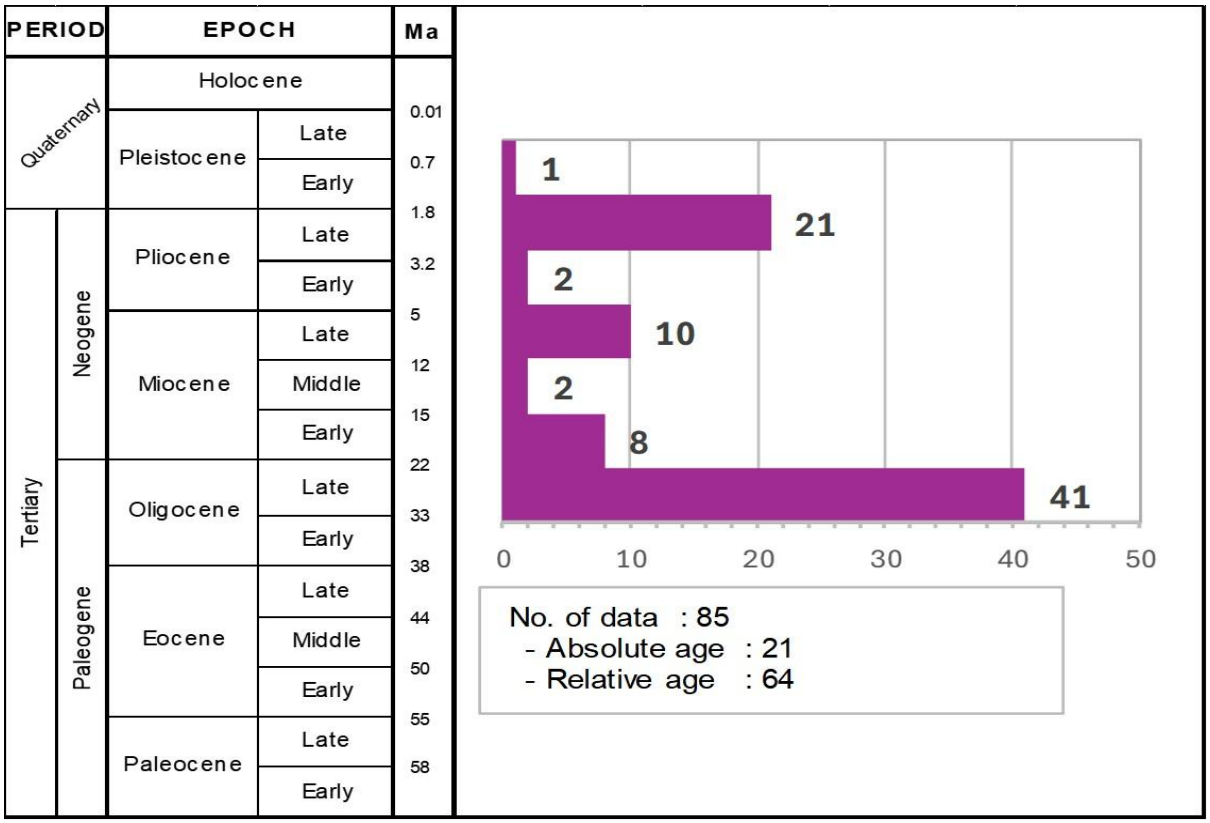


Figure 3. Age distribution of LSE gold mineralizations in Indonesia

Vein and Breccia Textures

Assessment on the genetic relationships among the various vein and breccia textures could also be assessed to vector the exploration, e.g. in Cibaliung (Angeles et al, 2002) and in Kerta (Lubis et al, 2012). Sinter that could indicate shallow level LSE system, commonly has various textures, e.g. fine banding/ lamination and even brecciations (Figure 6).

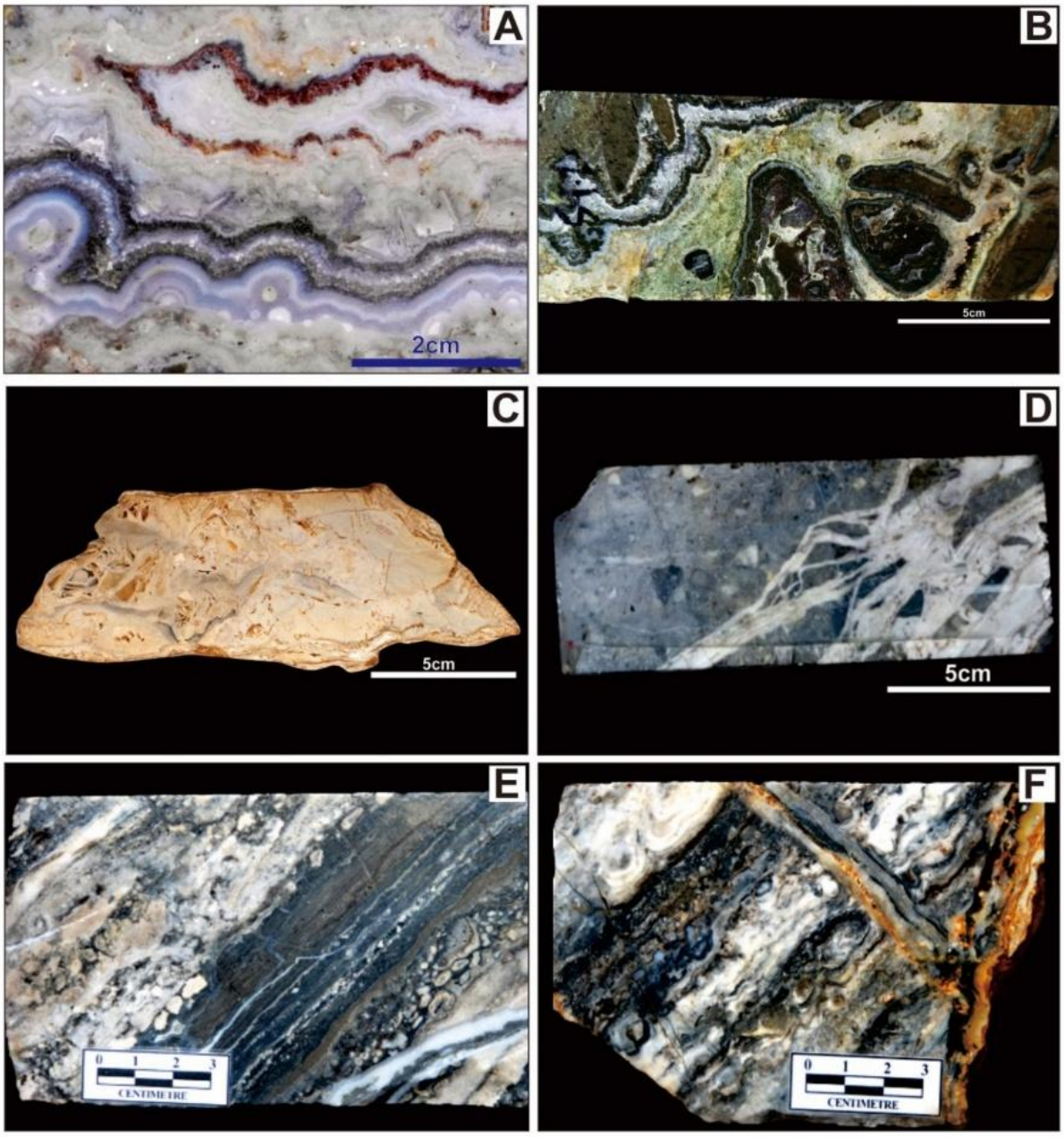


Figure 4. Selected textures of mineralized/ ore body and associated sinter of LSE. (A) Crustiform-colloform banding of quartz-amethyst with sulfides (dark color along the bands), (B) Cockade, crustiform banding surrounding isolated fragments of base metal sulfides and wall rocks, (C) Lattice bladed pseudomorph calcite, associated with quartz-chalcedony and few clay, (D) Quartz vein swarm crosscutting the silicified hydrothermal breccias, (E) Banded – laminated silicieous sinter, and (F) Banded sinter, cross cut by late stage quartz – chalcedony vein. (E) and (F) are from Kerta (Lubis et al, 2012).

Hydrothermal Fluid Salinity

Salinity data (of fluid inclusion studies) which is only available for 27 deposits/ occurrences showed various intensities of salinity (wt% NaCl), i.e. 3 deposits/ occurrences could be grouped as having high salinity (>10 wt% NaCl), 5 of them fall as moderate salinity (5 – 10 wt% NaCl), and the others (19) are less saline (<5 wt% NaCl) – see (Figure 7). Elevated salinity may suggest a closer association or influence of hydrothermal fluids by magmatic sources. It is interesting that 2 deposits/ occurrences with high salinity characteristic are associated with high Pb-Zn systems, e.g. Ciemas (Zhang et al, 2015) and Gunung Limbung (Alderton & Sudharto, 1987).

Review on the Au and Ag contents revealed that in majority the Au+Ag appear without association with other minerals/ elements. However, 14 of them (16.5%) are associated with base metal sulfide (galena and sphalerite), 8 of them (9.4%) in close association with As and Sb, and another 8 (9.4%) having close relation with Mn-oxides (Figure 7).

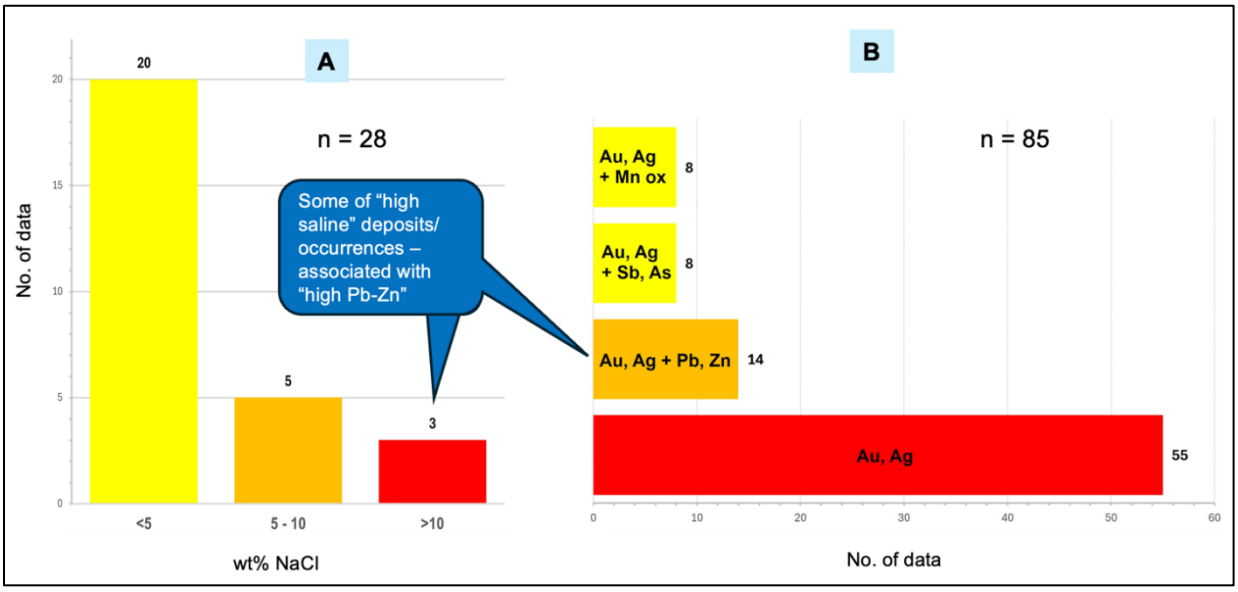


Figure 5. Associations of (B) Au+Ag contents with base metals (Pb, Zn), Mn-oxides, and other elements (As, Sb), and (A) with salinities of fluid inclusion data.

Hydrothermal Alteration

Hydrothermal alterations are mainly characterized by pervasive widespread alteration in the favorable host rocks or enveloping the veins/ mineralized zones comprising in general silica/ quartz-carbonates-illite-adularia and disseminated pyrite at various intensities and changing outward to propylitic (chloritic) alteration. It has been assessed that the areas of alteration footprints range from 10 ha (for a small occurrence) to more than 15,000ha (as a mineralized district, e.g. Masuparia – (Thompson et al, 1994).

Ore Grade

For the assessment of gold endowment/ inventory, of 85 deposits/ occurrences, 53 (62.4%) have resource +/- reserve data, and it accounts to 1,251 tons Au. The Au grades are ranging from 0.64 g/t to 22.00 g/t (e.g. Kencana, a satellite of Gosowong, c.f. Silitonga, 2013) – see Figure 8. Comparison of the number of gold content with the size of alteration footprint shows relatively subtle correlation – see Figure 9. It is understandable, since the data of alteration footprint represent surface situation that could be overlain by young rock cover preventing the alteration exposures (e.g. Kerta – Lubis et al, 2012). The other aspects that could influence the alteration distribution is the host rock types, structures, and the life/ duration of the paleo-hydrothermal process in the area.

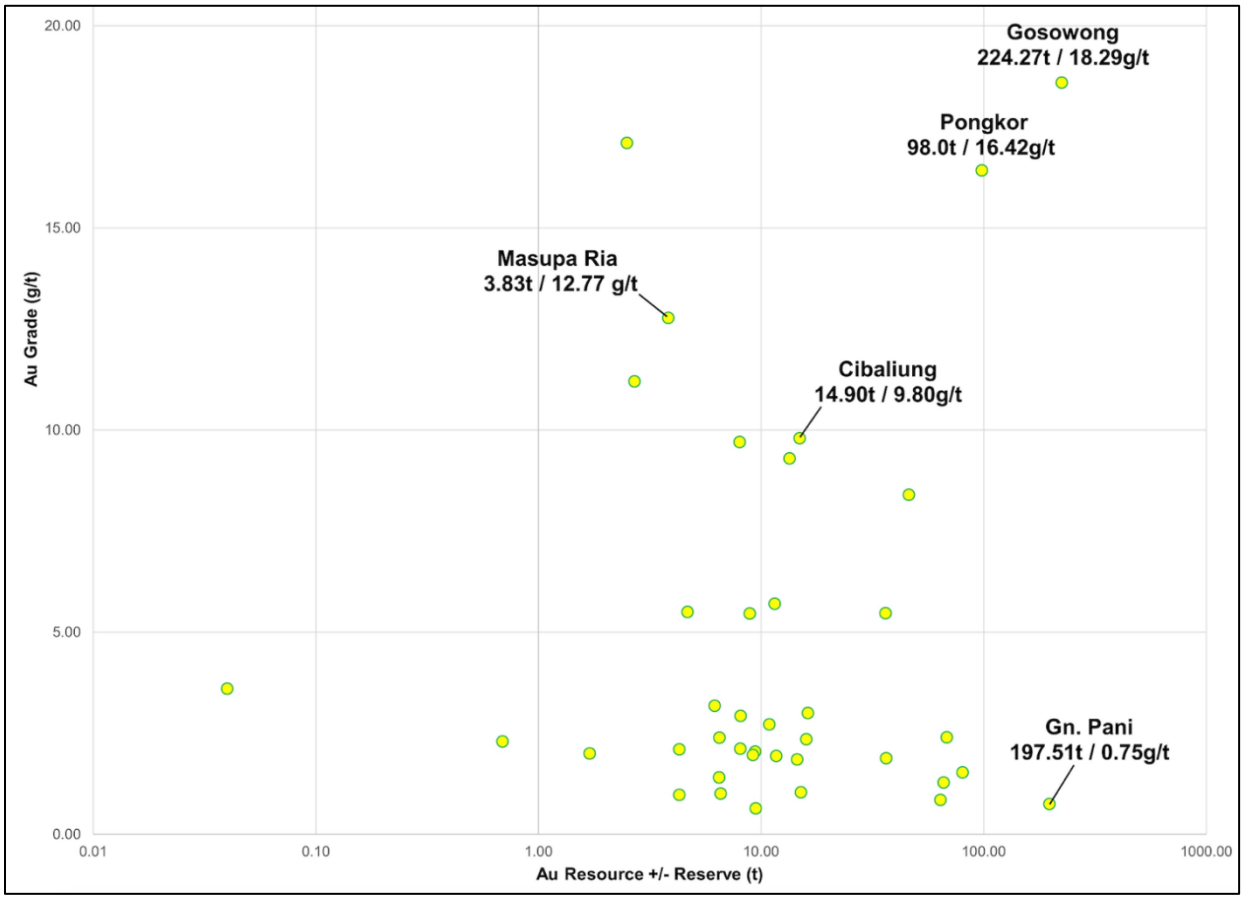


Figure 6. Gold contents vs their grades of the Indonesian LSE deposits (3.83t/ 12.77 g/t: first number is Au resource + reserve; second number is Au grade).

Exploration Implications

Exploration for LSE gold deposits in Indonesia during several past decades has provided some lessons for explorers. Mining and exploration of LSE gold deposits historically had been started since the Dutch era (end of 19th century), and apparently with simpler understanding on the mineralization system. Quartz veins and/ or vein (including breccia) zones with gold and base metal contents were the main targets of exploration, until the concept/ model of epithermal gold introduced and applied in the modern exploration era of Indonesia (after the 70's). Some old

deposits discovered by the Dutch such as Lebong Tandai, Lebong Donok, Cikotok-Cirotan have been redefined and redeveloped into second phase mining in the 70-80's. Later, some discoveries had been made e.g. Pongkor in 1988 (Basuki et al, 1994) and Gosowong in 1993 (Carlile et al, 1998; Carlile, 2022). Those two discoveries had given important lessons, i.e. (1) Pongkor is situated in the area that have been geologically mapped as Quaternary volcanics, supposed to be a cover, and (2) Gosowong discovery was started by the identification of a small quartz vein outcrop in Tobobo creek during the follow up works of stream sediment anomalies (Carlile et al, 1998).

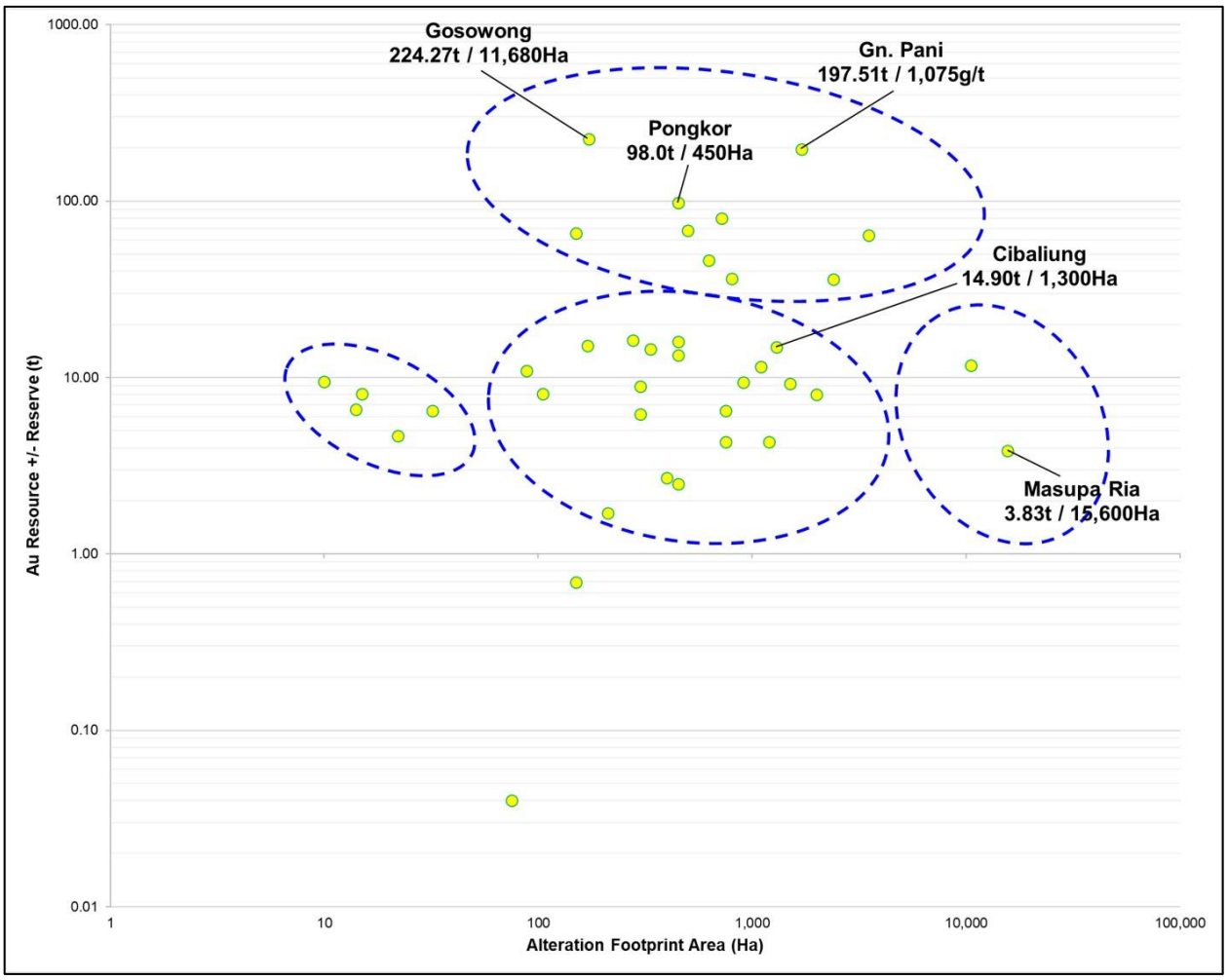


Figure 7. Alteration footprint areas vs gold contents of the Indonesian LSE deposits (14.90t/ 1,300Ha: first number is Au resource + reserve; second number is alteration footprint area).

Further exploration programs that have resulted in recent discoveries or re-definition of LSE gold deposits in general have been vectored based on the comprehensive assessment of the targets, started from evaluation of tectonic and regional geology, understanding on the local geology (what rock formations acting as host rocks and precursor of the possible mineralizations, as well as what rock types as covers). The understanding on the magmatic/ volcanic affinities (e.g. silicic/ acid vs intermediate/ andesitic volcanisms) is also important, as both magmatic systems would create different environments for the development of LSE mineralization. For example, in the 32.9%.

Concluding Remarks

The ideal system of LSE gold deposit as modelled from surface/ shallow to root levels, and published by many experts (e.g. Buchanan, 1981; White & Hedenquist, 1990; Corbett & Leach, 1998; Sillitoe & Hedenquist, 2003) in general could fit (although usually only a part of it) with the identified Indonesian LSE systems so far. The improved understanding of Indonesian LSE deposits particularly on the tectonic and geological setting, controlling structures, mineralized body shapes and metal contents, alteration system and size with regards to the LSE environmental levels (e.g. the importance of sinters, although they are low grade or barren), would reduce the challenges on recognition and identification of the LSE signatures. Exploration approaches introduced by White et al (1995) could be improved based on the current understanding of the Indonesian LSE system so far, that can be summarized as follows:

- Establishing the character of the geological environment at the time of mineralization, that could be used in assessing the hydrogeological condition prevailed during mineralization, in relation to likely forms and controls of the mineralization. It should commonly be possible by observation of the volcanic rock types and interpretation of volcanic facies.
- Once the likely volcanic environment could be established, the types, distribution, and zoning of hydrothermal alteration, combined with observations of the vein textures and mineralogy, as well as the presence of sinter and other shallow level alteration signatures, will allow the interpretation on chemical nature of the system, the level at which the system exposed, and on the possible localizing controls.
- The exploration methods that are commonly used and have proven records in vectoring to the discoveries include: regional and semi detailed geological mapping and prospecting, regional geophysical survey (airborne magnetic-radiometric), stream sediment prospecting (-60# to -160# SS; BLEG), detailed follow up mapping, soil sampling, ground geophysics (magnetics, IP/ resistivity-chargeability, CSAMT), trenching – rock sampling, and drilling.

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