Indonesian Journal of Economic Geology (IJEG)
Volume I No. 2, September 2025: 131-157 e-ISSN 2809-1094

GEOLOGY OF POBOYA DEPOSIT: METAL ZONATION AND VEIN TEXTURE CHARACTERISTICS

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Received Date: 3 March 2025, Accepted Date: 10 August 2025, Published: 30 September 2025

Abstract

The Poboya gold deposit is well known as a low-sulfidation epithermal Au-Ag deposit hosted in metamorphic rocks. The Poboya Project consists of two main prospects: River Reef and Hill Reef 1, located in Poboya, Palu City, Central Sulawesi Province. Gold mineralization is characterized by a bulk average Au: Ag ratio of approximately 1:2, although the ratio varies by elevation and ore zone, with low base-metal (Cu-Pb-Zn) grades of <100 ppm and the presence of quartz veins exhibiting bladed, chalcedonic, colloform, and crustiform textures. Gold in Poboya is generally deposited as electrum within quartz and platy calcite with a fine grain size averaging 10 microns. Vertical zoning at River Reef demonstrates a consistent increase in average gold grades for every 50-meter decrease in elevation. The highest grades, averaging 10 g/t Au, are concentrated between 50 and 100 mRL. These high-grade zones strongly correlate with crustiform and colloform quartz textures, suggesting that fluid boiling was the primary mechanism for gold deposition. Furthermore, fluid inclusion analyses of associated crustiform calcite veins yield homogenization temperatures (Th) ranging from 200°C to 250°C. The characteristics of the Au-Ag metal zoning indicate a regular grade distribution, with the dip direction of mineralization in several ore zones consistent with the dip direction of the structural zone, and contact between schist and gneiss, indicating structural and lithological control of mineralization. The variation in mineralization thickness reflects the pinch-and-swell patterns at the structural openings.

Keyword: Gold, Metamorphic rock, Metal zonation, Vein texture, Poboya

Introduction

PT Citra Palu Minerals (CPM) is a mining company that holds a 6th Generation Contract of Work (CoW) in Central Sulawesi and South Sulawesi, covering an area of 85,180 hectares, comprising five blocks: Block I Poboya, Block II Winehi, Block IV Anggasan, Block V Moutong, and Block VI Roto. The Poboya project is a low-sulphidation epithermal mineralization prospect located in Block I Poboya. The gold deposits are found in quartz veins mineralization zone hosted in metamorphic rocks of the Palu Metamorphic Complex, intruded by granite. The veins zone is composed of quartz and quartz carbonate with small amounts of calcite, pyrite, and gold. The textures within the quartz veins indicate multiphase deposition, such as colloform, crustiform, colloform-crustiform, and breccia (vein breccia and wallrock breccia).

Epithermal deposits were first introduced by Lindgren (1933) as a classification for shallow crustal hydrothermal ore deposits formed under low-temperature and low-pressure conditions. The term was defined based on its relationship to volcanic stratigraphy and direct analogy with the occurrence of minerals and textures found in modern geothermal systems. Two types of epithermal deposits are recognized: high-sulfidation and low-sulfidation, the primary mineralization of which is gold, the main economic metal, both of which show distinct

geochemical associations (White and Hedenquist, 1995). Low-sulfidation deposits commonly form at shallow crustal levels, generally <1 to 1.5 km below the paleosurface or paleowater table and at temperatures below 300°C, in hydrothermal systems dominated by meteoric water. Metals grade from gold and possibly copper-bearing at depth, through gold with base metals at intermediate levels, to gold-silver bearing at the highest crustal levels (Corbett and Leach, 1997).

Previous studies have established Poboya as a metamorphic-hosted, low-sulfidation epithermal Au-Ag deposit. However, the relationships between metal distribution, grade-thickness variation, vein textures, host-rock contacts, and structural architecture have not yet been examined in an integrated deposit-scale framework. Earlier studies have mainly focused on the general deposit characteristics, host rocks, hydrothermal alteration, mineralogy, and selected fluid-inclusion data. Consequently, several important aspects remain insufficiently understood, particularly the relationship between Hill Reef 1 and River Reef, the position and possible vertical migration of the boiling zone, and the absence of typical base-metal enrichment at deeper levels of the system. The study attempts to apply vein textures and multi-element geochemistry as reliable exploration vectors within the thickly covered and structurally controlled Poboya mineralization system.

This study aims to define the vertical and lateral zonation of precious and base metals at Poboya and to evaluate their relationships with vein textures, quartz abundance, sulphide occurrence, host lithology, and structural geometry. The specific objectives are to: (1) characterize the distribution of Au, Ag, base metals, and pathfinder elements by elevation and along strike at River Reef and Hill Reef 1; (2) evaluate the relationships between Au grade, approximate true thickness, quartz abundance, dominant vein texture, and sulphide abundance; (3) determine whether the high-grade mineralized interval is spatially associated with textural and mineralogical properties, and (4) establish practical geological indicators for deeper and lateral exploration through the combined application of metal zonation, vein-texture distribution, and Au gram-meter values.

Exploration History

The Poboya project, which includes the River Reef and Hill Reef 1 deposits, was originally owned by PT Rio Tinto Group (RTG) in 1997 after being granted an exploration license. In 1992, Rio Tinto conducted a regional bulk-leach extractable gold (BLEG) Au/Ag sampling program in accessible areas of Central Sulawesi and identified the Poboya area for follow-up sampling based on BLEG anomalies of 27 ppb Au and 51 ppb Ag. The Poboya project was discovered in 1993, when extensive clay alteration zones were mapped, and quartz vein outcrops in the Pondo River were chip-sampled, yielding very high gold grades, including 55 m at 47 ppm Au and 115 m at 15 ppm Au (Wajdi et al., 2012).

Exploration activities at Poboya have been conducted in phases since the early 1990s. The initial program included a ground magnetic and induced polarization (IP) survey in 1993, followed by mineralization evaluation through 11 core drill holes totaling 2,861 m in 1996, along with mapping and sampling. In 1998, a follow-up drilling campaign of 22 holes totaling 4,494 m resulted in a preliminary resource estimate. Furthermore, a 27 km CSAMT survey indicated potential down-dip mineralization. Following the legal takeover of PT Citra Palu Minerals by Bumi Resources Minerals, exploration activities focused on drilling at the River Reef and Hill Reef 1 prospects. The development of the Poboya project is also supported by other studies, including petrography, mineragraphy, geotechnical and geohydrology studies, acid mine drainage for mine development, and aeromagnetic studies, including further CSAMT for exploration development. In 2024, total drilling across both prospects exceeded 100,000

meters, resulting in a mineral resources estimate of 40.2 Mt @ 3.5 g/t Au and 8.0 g/t Ag (AMC, 2024).

Regional Geology

The basement rocks in the central and northern parts of the province form a geological belt known as the Central Sulawesi Metamorphic Belt, which is distributed restricted to the central and northwestern parts of the province (Figure 1). This belt is interpreted to have formed as a result of the collision between Gondwana fragments and the active Asian margin during the Late Oligocene to Early Miocene. This belt consists of the Palu, Karossa, and Malino Metamorphic Complexes, which are composed of continental fragments derived from the Australia–New Guinea margin (van Leeuwen et al., 2007).

The Palu Metamorphic Complex (PMC) extends from the central part of the province, within the Palu Zone, northward to the neck of the Sulawesi Peninsula. The PMC consists of biotite gneiss, biotite schist, amphibole, and amphibolitic schists. Several higher-grade metamorphic rocks also occur in this complex, such as granulite, eclogite, and garnet peridotite. This metamorphic complex is derived from Permo-Triassic metagranitoids and metasediments of Australia-New Guinea, metabasites of mid-ocean ridge basalts affinity, and Sundaland-origin rocks. The PMC is subsequently overlain by Tertiary volcano-sedimentary strata known as the Tinombo Formation. Late Cenozoic granitic rocks intrude the basement and the volcano-sedimentary formation throughout the area. A rapid exhumation event occurred in the area and led to extensive weathering, which resulted in Quaternary Celebes Molasse sediments. The sediments flank the uplifted metamorphic core complex along the neck of Sulawesi (Maulana et al, 2019; Syafrizal et al, 2017).

The most prominent structural feature in NW Sulawesi is the Palu or Palu-Koro Fault, which is a transtensional fault zone. It can be traced from Donggala at the tip of the Palu Bay for 300 km in a SSE direction. In a northerly direction, it may link up with the North Sulawesi Trench, which bounds the Celebes Sea Basin to the south. Near Palu, the fault zone consists of a major pull-apart basin that terminates some 40 km to the SSE of this town. The basin is bounded to the west by a major fault, forming a 2300 m-high escarpment, and its sedimentary infill dips gently westward off an unconformity along the eastern margin (van Leeuwen, 2005).

Research Methods

This study combines geological, structural, geochemical, mineralogical, and drilling data from the River Reef and Hill Reef 1 prospects. The analysis is based mainly on more than 100,000 m of diamond drilling completed during the 1998, 2012, and 2019 to February 2026 exploration campaigns. Surface mapping, drill-core logging, drill-hole surveys, mineralized-domain interpretations, and assay results for Au, Ag, Cu, Pb, Zn, As, Sb, Mo, and Hg were used where available. Petrography, mineragraphy, and earlier fluid-inclusion studies were also reviewed to understand better the mineral assemblages, gold occurrence, mineral paragenesis, and conditions of the mineralizing fluids. Historical BLEG sampling, geophysical surveys, and regional exploration results were used mainly to provide geological context.

Geological and assay data were compiled using unique drill-hole and sample identifiers. The database was checked for duplicate records, missing or overlapping intervals, inconsistent depths, invalid coordinates, and discrepancies between collar, survey, geology, and assay records. Drill-hole traces were calculated from collar and down-hole survey data and referenced to meters Relative Level (mRL). Unsampled intervals were retained as null values, while assays below the detection limit were handled consistently with the project database

procedures. Only data that passed the relevant campaign QA/QC requirements were included in the quantitative analysis.

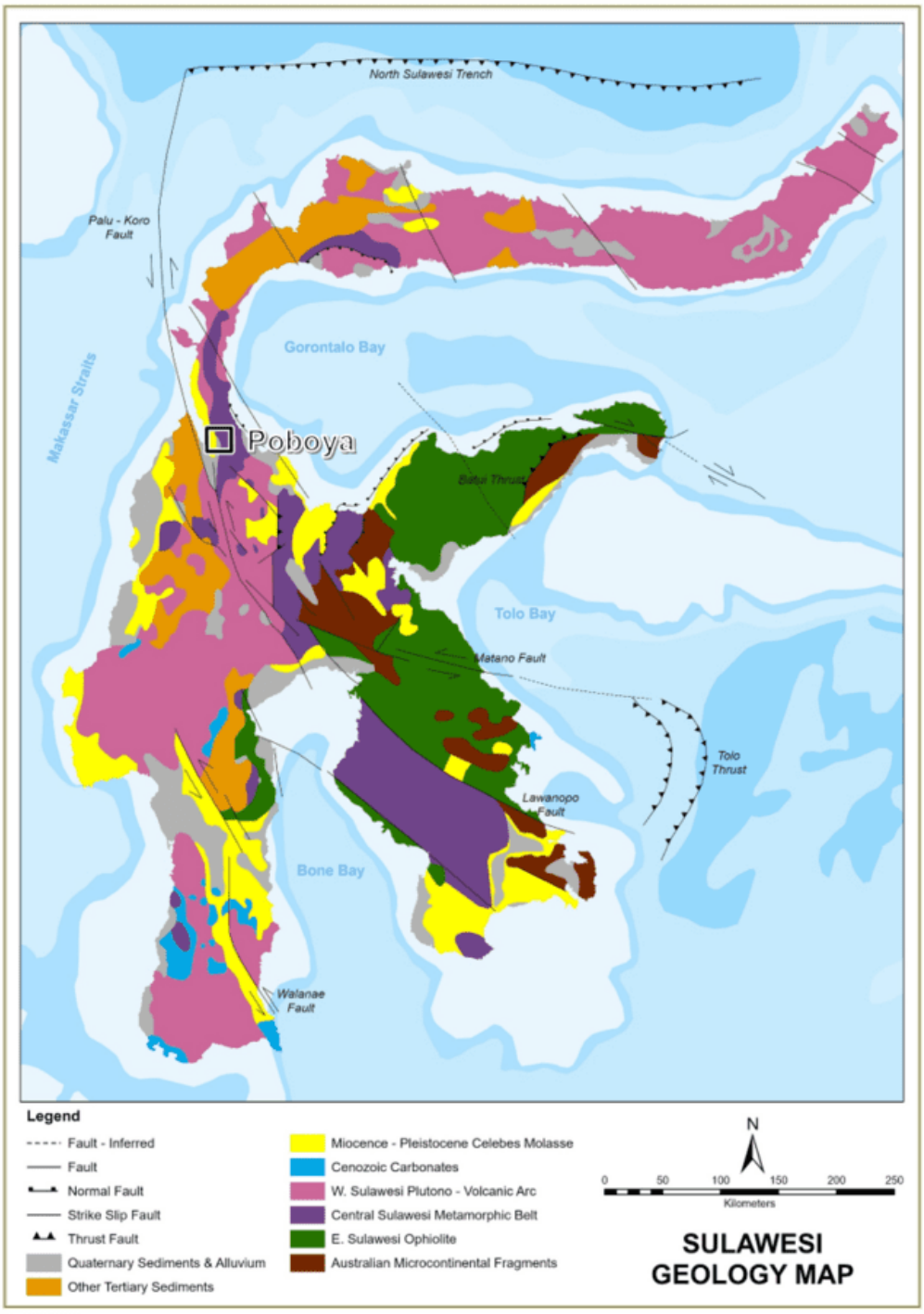

Figure 1. Simplified geological map of Sulawesi after Hall & Wilson (2000), in Calvert and Hall, 2007

Mineralized intercepts were defined using geological and structural boundaries rather than assay grade alone. Average grades were weighted by sample length, and down-hole intercepts were converted to approximate true thickness using the relationship between the

drill-hole trajectory and the local orientation of the mineralized zone. Au gram-meter values were calculated by combining the length-weighted Au grade with the interpreted true thickness.

Vertical metal and vein-texture zonation was examined using 50 m elevation intervals from approximately -100 to 650 mRL. Intercepts that crossed an elevation boundary were divided where possible or assigned consistently based on their three-dimensional midpoint. The analysis considered sample and intercept numbers, total sampled length, mean and median grades, and data variability where sufficient data were available. Lateral zonation was examined using cross-sections and longitudinal sections oriented parallel to the mineralized trends. Intercept positions, grades, approximate true thicknesses, and Au gram-meter values were projected onto these sections to assess grade continuity, ore-shoot plunge, structural control, and changes in mineralized thickness. Contours and interpretations were limited to areas with adequate drilling support.

Geology of Poboya

The Poboya project is located approximately 12 km northeast of Palu City. The local geology of the Poboya project lies within the Palu Metamorphic Complex, which consists of metamorphic schist and gneiss intruded by granite. Unconformably, the PMC is overlain by a molasse deposit. Vein fragments within the molasse indicate that mineralization formed before the molasse was deposited. Two main mineralized zones have been identified from drilling at the Poboya Project: River Reef and Hill Reef 1. CSAMT interpretation results also support the interpreted geometry of these mineralized zones, particularly along high–low resistivity contact anomalies (Geoservices, 2024).

The Poboya Project is located on the eastern side of the major pull-apart basin, within a northwest-southeast trending structural corridor east of the Palu-Koro Fault. The presence of the Palu–Koro Fault has an important role in controlling the development of Poboya fault systems, which serve as the main pathways controlling the formation of mineralization. The low-sulfidation Au-Ag epithermal mineralization in Poboya is associated with structures that trend northwest–southeast (NW–SE), subparallel to the main Palu–Koro Fault, with a relatively gentle dip to the southwest (Marten, 1999).

Lithology

Based on geological mapping and drill core logging, several lithological units have been identified within the Poboya Project. From oldest to youngest, these comprise metamorphic schist, gneiss, feldspar porphyry, granite, molasse, and alluvium. Feldspar porphyroblast schist occurs as an intercalated unit between the schist and gneiss. The stratigraphic relationship among these lithologies indicates an unconformable contact, with the schist and gneiss forming the basement rocks intruded by granite and the molasse sequence overlying them unconformably. These lithological units were identified through petrographic analyses conducted by CPM and supported by previous studies (Yuwono, 2012; Rivai, 2016; LAPI, 2021; White, 2025).

Schist (Biotite and Ampibolite Schist)

Schist is the oldest lithological unit found in the Poboya project. This unit occurs at the base of the drillhole intercepts and marks the mineralization's footwall. The schist is dark green to greenish gray, shows well-developed foliation, and is characterized by lepidoblastic and nematoblastic textures. It is predominantly composed of biotite and amphibolite schists and is interpreted to have formed from sedimentary protoliths.

Feldspar Porphyroblast Biotite Schist

Feldspar porphyroblast is locally present in the drill cores and occurs as an intercalated unit between the gneiss and schist. The feldspar porphyroblast schist is dark gray in color, with weak foliation, and is characterized by coarse feldspar porphyroblasts set within a thinly foliated mafic mineral matrix. The feldspar porphyroblasts are coarse-grained, ranging from 0.5 to 1 cm in size. This rock displays a foliation fabric texture similar to that of the surrounding biotite schist, with foliation predominantly defined by the preferred orientation of biotite. Compared with the other metamorphic lithologies, hornblende is more abundant in this unit. Chlorite commonly occurs as an alteration product of biotite and hornblende. Accessory minerals are also aligned parallel to the foliation, although this fabric is locally deflected around the large feldspar porphyroblasts (Rivai, 2016).

Gneiss (Biotite Gneiss)

Gneiss is the primary host rock for most mineralization in the Poboya Project. This metamorphic unit is widely distributed throughout Sulawesi. The gneiss is characterized by alternating light-colored and dark gray foliation bands, moderate foliation, and granoblastic to lepidoblastic textures. This gneiss is interpreted to have originated from a granitic protolith with a mineral assemblage dominated by feldspar and mafic minerals.

Granite

The granite unit is widely distributed in the northwestern part of the Poboya project. It is light gray to pinkish gray in color and shows a phaneritic texture, with coarse-grained K-feldspar phenocrysts set within a felsic groundmass. The granite is composed primarily of quartz, orthoclase, and plagioclase.

Mollase

Molasse is a cover unit that is widely distributed across the Poboya area. It consists of semi-consolidated deposits, generally dominated by conglomeratic clasts and clay-to-sandy materials with poor sorting. The molasse is interpreted as clastic debris derived from uplift and erosion during late-stage tectonic uplift and deposited in extensional to transtensional basins associated with block faulting. Molasse is predominantly composed of clastic sedimentary rocks containing a variety of clasts derived from pre-existing rocks.

Alluvium

This unit represents recent alluvial deposits and is commonly encountered in drill holes located near the Pondo River drainage area. The alluvium consists of unconsolidated river deposits composed of gravel, silt, and sand-sized fragments that are rounded and poorly sorted. The clasts are derived from a mixture of lithologies, including schist, gneiss, granite, and vein material.

Hydrothermal Alteration

The alteration types in the Poboya project mineralized area consist of silicification, argillic and propylitic assemblages. Hydrothermal alteration is indicated by the abundance of veinlets dominated by calcite and quartz veins. Several analyzed samples show cross-cutting vein relationships, where earlier veins are overprinted by younger ones, indicating multiple phases of hydrothermal alteration. Based on petrographic analysis of drill core samples, all examined specimens show evidence of hydrothermal alteration with variable intensity, ranging from weak to very strong. Alteration of the primary lithologies ranges from moderate to intense. It has produced secondary chlorite, illite, epidote, calcite, quartz, albite, K-feldspar, and rare actinolite, graphite, smectite, titanite, and/or rutile (Zhang and Merchant, 1996; White, 2025).

Propylitic alteration, characterized by common chlorite and epidote, is best seen in samples from 100-200mRL elevation, which also contains chlorite and epidote, but illite is more abundant in this sample, meaning it is transitional between phyllic and propylitic. Intense

phyllic alteration affects rock fragments in one of the quartz-calcite veins from 170mRL elevation, which are composed of quartz, illite, and calcite, and lack chlorite (White, 2025).

Relict high-temperature propylitic alteration is preserved in the brecciated gabbro, in which minor actinolite is preserved, though most has been subsequently replaced by chlorite and epidote. A thin band of smectite was also tentatively identified within one of the calcite veins. Smectite may indicate low-temperature argillic alteration (<150°C), possibly related to late-stage cooling, waning hydrothermal activity, or meteoric overprint; this interpretation should be confirmed by clay mineralogy and paragenetic relationships.

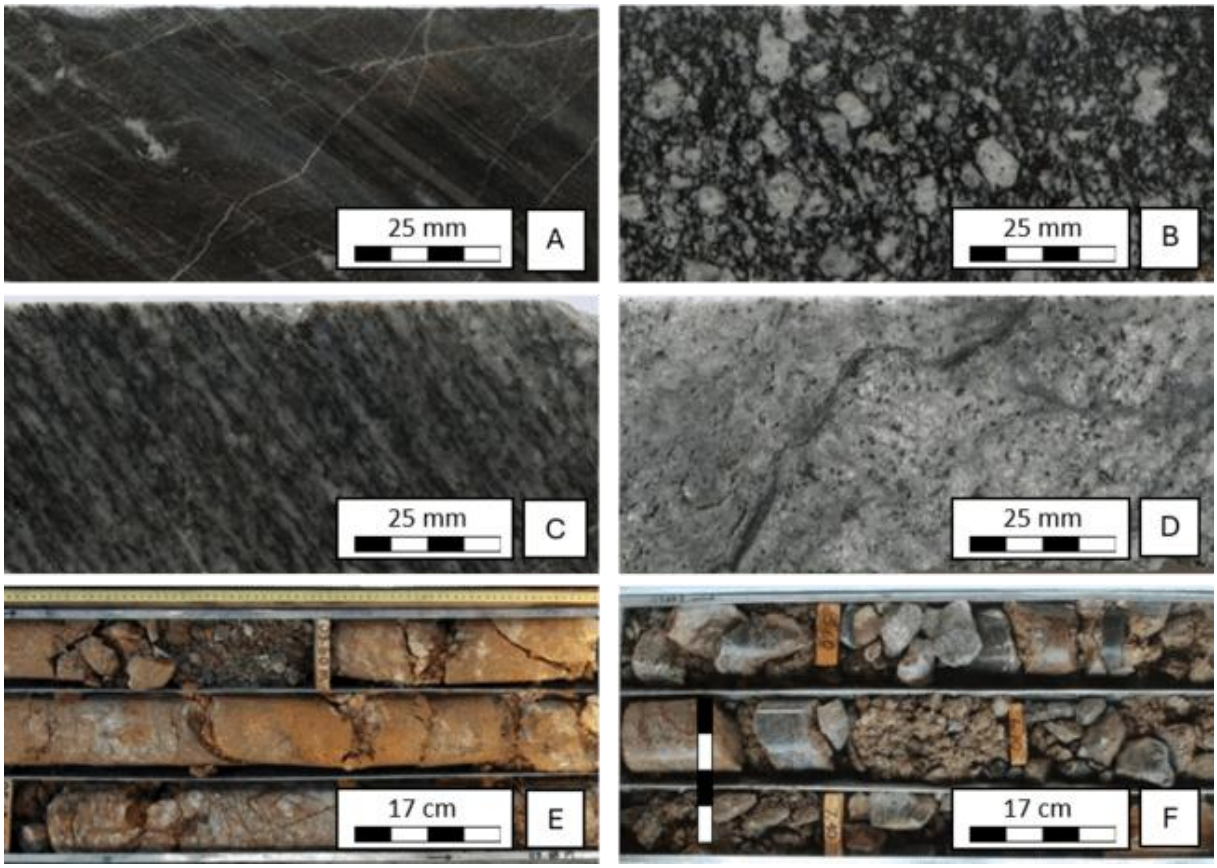

Figure 2. The rock units in the Poboya area, from oldest to youngest, are (a) schist, (b) feldspar porphyroblast schist, (c) gneiss, (d) granite, (e) molasse, and (f) alluvium.

Surface alteration is not significantly observable due to the thick molasse cover over the surface in the Poboya project area.

Ore Mineralization

Ore mineralization at the Poboya project indicates that the low-sulfidation Au–Ag epithermal system is associated with a vein zone comprising quartz, quartz–carbonate, and carbonate veins. Within these quartz–carbonate zones, characteristic epithermal textures such as colloform–crustiform banding, bladed calcite pseudomorphs, chalcedonic quartz, and cockscomb-banded quartz provide strong evidence of a multiphase evolution of hydrothermal fluids.

The characteristics of the Poboya Project deposit suggest that the veins formed under low-temperature, near-neutral-pH conditions, which are typical of low-sulfidation deposits. The mineralized zones are associated with multiphase quartz–carbonate veining and breccia veins, commonly showing banded, chalcedonic, and bladed textures.

Gold mineralization in the prospect area is interpreted to be related to bladed and banded chalcedony textures within quartz–carbonate veins, with thicknesses ranging from 1 cm to >10 cm and variable orientations and grades. Minor banded chalcedonic textures within quartz–carbonate stockwork zones are commonly associated with grey sulphide mineralization at the margin of veinlets.

The mineralization zone hosts several distinct vein types and structural styles, classified as follows:

1. Quartz ± Carbonate Veins: Comprising >90% quartz with subordinate carbonate minerals and <10% wall-rock materials. These veins constitute the primary host for mineralization and locally exhibit minor brecciation.
2. Vein Breccia: Quartz veins with breccia textures, consisting of earlier-stage quartz vein clasts supported by a later-stage hydrothermal quartz matrix and cement.
3. Wallrock Vein Breccia: Brecciated veins containing >10% host-rock fragments embedded within a quartz matrix and cement.
4. Stockwork: A multidirectional network of intersecting quartz veinlets typically comprising three or more randomly oriented sets that fracture-fill the host rock.
5. Sheeted Veins: Arrays of parallel to sub-parallel planar quartz veins crosscutting the host rock. To meet the classification for this type, the rock mass must contain a minimum of 5% quartz veining by volume.
6. Carbonate Veins: Comprising >90% carbonate minerals with subordinate quartz and <10% wall-rock materials.

Mineragraphic Analysis

CPM conducted a mineragraphy analysis by submitting 10 samples for examination. The primary objective of this analysis was to obtain a more detailed understanding of gold deposition. The results indicate that pyrite is present in all samples, accompanied by electrum in seven samples, as well as arsenopyrite, chalcopyrite, sphalerite, tetrahedrite, and native silver. Pyrite is present in all these samples, occurring as an alteration mineral, in veins, and within the breccia cement. It is mostly subhedral to euhedral, and while it is generally very fine-grained, there are coarse euhedral pyrite crystals in some of the veins. Some of the pyrite is weakly bireflectant and has rhombic rather than cubic shapes, meaning that there is some arsenopyrite and/or arsenical pyrite in at least some of these samples.

Pale yellow electrum was observed in seven samples, mostly occurring within platy quartz–calcite veins. It is also found in altered host-rock fragments and in breccia cement. Electrum is commonly associated with quartz, calcite, and calcite veins. Its grain size, occurrence, and associated and enclosing minerals are highly variable, with an average size of approximately 10 μm (Hawke and Leach, 1995; White, 2025)

Another mineral, tetrahedrite, was tentatively identified as a soft grey mineral within calcite veins. Elongated ilmenite crystals appear to be a primary component of hornblende hornfels. The samples also contain small, disseminated anhedral grains of sphalerite and chalcopyrite, as well as minor inclusions of two unidentified minerals within chalcopyrite.

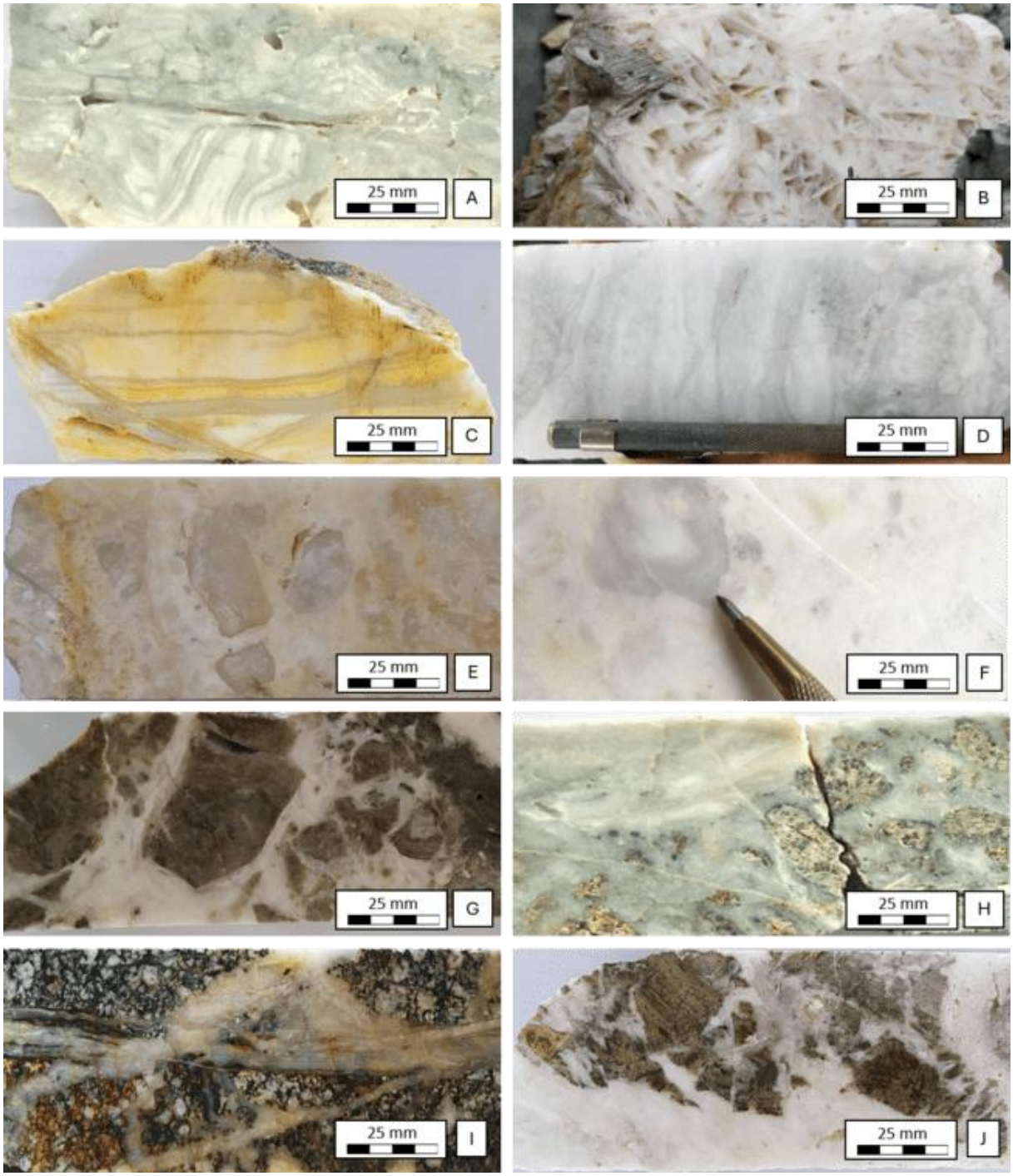

Figure 3. Mineralization-bearing vein types in the vein zone. (a), (b) quartz vein, (c), (d) quartz-carbonate vein, (e), (f) vein breccia, (g), (h) wall-rock vein breccia, (i) quartz stockwork, and (j) carbonates vein

Mineragraphy samples show a typical low-sulphidation epithermal mineralization, with veins and hydrothermal breccias containing quartz, platy calcite, pyrite, and adularia. There is evidence of early high temperature alteration, though the main stage of vein deposition coincides with phyllic/propylitic alteration.

Table 1. Summary of Gold Size and Location in Mineragraphy Samples

Project	Gold size avg (um)		Max gold size (um)		Gold location	Gold in samples
	Width	Length	Width	Length		
Poboya	10	6	54	52	in Q/Cal or platy Cal	154
	3	2	7	5	in Cal with Td or Py	27
	8	6	20	20	in Py in Qvein and in Bx matrix	10
	6	5	6	5	in Q in Qvein	2
Total	**9**	**6**	**54**	**52**		**193**

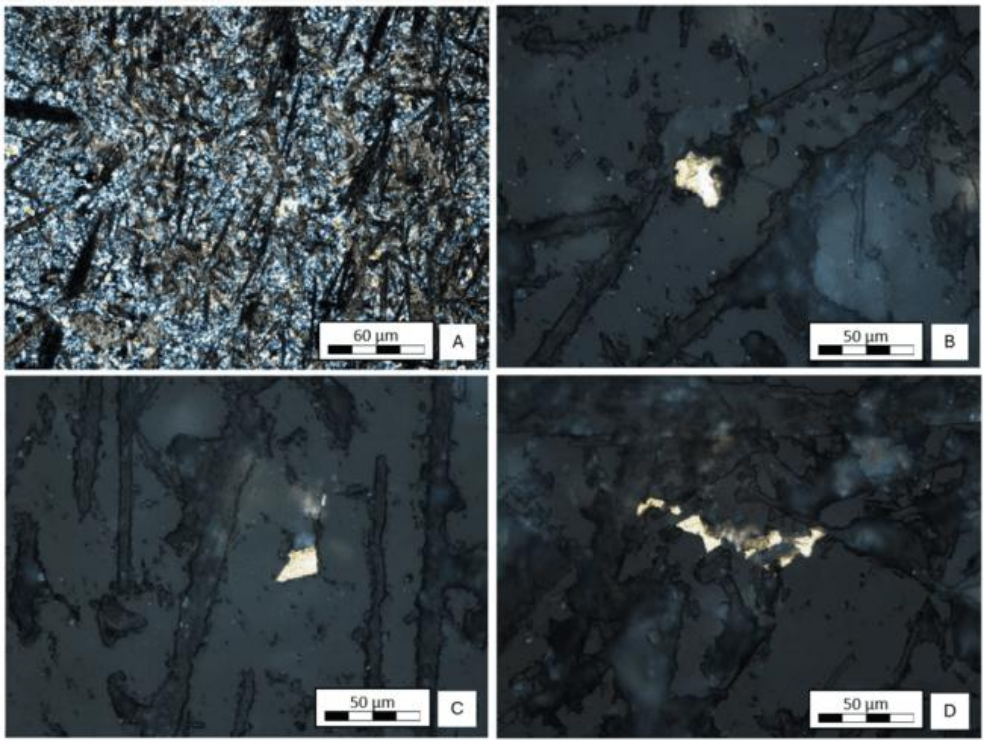

Figure 4. Mineragraphy features: (a) calcite crystals within fine-grained quartz, (b) anhedral electrum grains within quartz, (c) electrum grains within quartz–calcite veins, and (d) electrum within quartz–calcite veins.

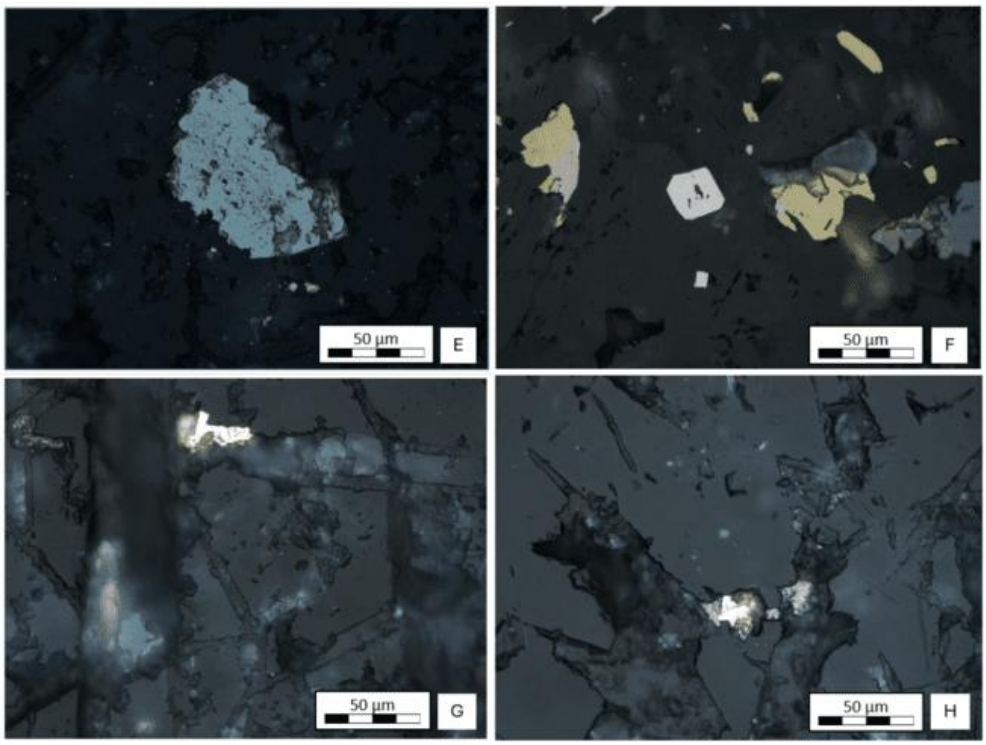

Figure 5. Mineragraphy features: (e) pyrite and electrum in calcite and quartz; (f) pyrite, sphalerite, and chalcopyrite; (g) electrum, galena, and pyrite grains with hessite inclusions in platy calcite, quartz, and adularia; (h) pyrite, electrum, aguilarite, and other phases in platy calcite and quartz.

Gold mineralization is closely associated with veining and hydrothermal brecciation, with most of the gold associated with platy calcite and quartz within veins and in the matrix of hydrothermal breccias. Some of the gold is intergrown with pyrite and tetrahedrite(?), but mostly it occurs as individual grains that are included in quartz or calcite. Fluid inclusion analyses were conducted by CPM in 1996 and by a subsequent study in 2016 on several vein samples collected from the River Reef deposit. The fluid inclusions, which represent the ore-forming fluids responsible for the late stage of gold mineralization, are characterized predominantly by liquid–vapor two-phase inclusions. Evidence for fluid boiling is indicated by the coexistence of liquid-rich and vapor-rich inclusions within the same assemblages. The hydrothermal fluids at Poboya are further constrained by low salinities of approximately 0.3–0.7 wt.% NaCl equivalent and homogenization temperatures ranging from 200 to 250°C, consistent with low-salinity epithermal mineralization (Hawke and Leach, 1995; Rivai 2016).

Mineralization Characteristics and Metal Zonation

Surface geological mapping indicates that mineralization in the Poboya area is characterized by quartz vein mineralized zones, stockwork, and silicification, which extend along a NW–SE structural corridor. Surface data show that the Hill Reef 1 mineralized zone extends for 1.6 km with an orientation of N120°E toward the northwest and continues into the River Reef mineralized zone, which extends for 200 m with an orientation of N145°E in the southeastern part.

Drilling data indicate that the Hill Reef 1 mineralization extends to a depth of approximately 1,500 m strike length below the surface, with a strike of N120°E and a dip of 25°–30°, occurring from surface elevations of 680 mRL down to -380 mRL. In contrast, the River Reef mineralization extends to approximately 1,500 m strike length below the surface

with a strike of N140°E and a dip of 30°–35°, occurring from surface elevations of 375 mRL down to -25 mRL. The mineralization characteristics at Hill Reef 1 are defined by the presence of quartz vein zones, massive silicification, and gneissic stockwork, whereas River Reef is characterized by a main quartz vein zone and splay vein systems. A general classification of these characteristics is presented below.

Hill Reef 1 Mineralization

Vein Zone

- Vein zone is the main mineralized zone of Hill Reef 1, extending for 1,500 m with a strike of N120°E and a gentle dip of 20°–25°.
- The lithology is dominated by quartz veins, quartz–carbonate veins, and vein breccias, hosting low-grade mineralization ranging from 0.5 to 1 g/t Au.
- Quartz mineralization occurs within gneissic host rocks.

Quartz Hematite Stockwork Gneiss

- Stockwork Gneiss is a parallel mineralized zone located in the lower part (footwall) of the main Hill Reef 1 mineralized zone, sharing the same strike and dip. Mineralization is irregularly distributed.
- The mineralization consists of a quartz–hematite stockwork hosted within gneiss, with a high degree of oxidation. It contains very low-grade mineralization ranging from 0.2 to 0.5 g/t Au.
- This stockwork gneiss mineralization occurs below the main vein zone.

River Reef Mineralization

Main Vein (MV)

- Main vein is the main mineralized domain in the River Reef, extending for 1,500 m with a strike of N155°E and a gentle dip of 30–35°.
- The main vein mineralization forms a single primary ore body, which is subdivided into three main vein zones. The domain classification is based on grade characteristics. The main vein upper domain represents mineralization extending from the upper section to the surface, whereas the main vein lower domain generally contains higher-grade mineralization and represents the down-dip continuation of upper part. The main vein parallel domain is a mineralized zone that is subparallel below the main vein upper zone.
- The lithology is dominated by quartz veins, quartz–carbonate veins, and vein breccias.
- The lower boundary is defined by the presence of fault breccia.

Splay Vein (SPV)

- Splay veins represent the upper splay mineralization, which has a strike broadly similar to that of the main vein domain and a subvertical dip.
- The lithology is dominated by quartz, carbonate, and quartz–carbonate veins hosted within granite and gneiss wall rocks.
- This mineralized zone occurs both above and below the Main Vein zone.
- The splay vein domain can be subdivided according to its grade characteristics and mode of occurrence, as follows:
    a) Splay Vein Outcrop: This domain has a moderate average gold grade of 1–3 g/t Au and occurs at or near the surface (outcrop zone). It comprises five splay vein zones.

b) Splay Vein High Grade: This domain has a high average gold grade of 3–5 g/t Au and occurs at depth within the hanging wall of the Main Vein. It comprises eight splay vein zones.
c) Splay Vein Low Grade: This domain has a low average gold grade of <1 g/t Au and occurs at depth within the hanging wall of the Main Vein. It is characterized by stockwork mineralization and comprises five splay vein zones.

Data Analysis

The geochemical dataset for the Poboya Project was compiled from diamond drilling exploration programs conducted during the 1998, 2012, and 2019–present exploration campaigns. The analytical database includes Au, Ag, Cu, Pb, Zn, As, Sb, and Mo assays, with selected drill holes also containing multi-element ICP–OES data. The dataset used in this study incorporates all available drilling data up to February 2026.

Precious and base metal geochemistry was averaged over mineralized drill intercepts within the mineralized structures at River Reef and Hill Reef 1. The geochemical database used for metal zonation comprises the average elemental concentrations and Au gram–meter values for each mineralized drill intercept. Vertical metal zonation was evaluated using cross-sections subdivided into 50 m elevation intervals, whereas lateral metal zonation was assessed using longitudinal sections parallel to the mineralized trend, with contour maps generated for Au, Ag, and Au gram–meter values.

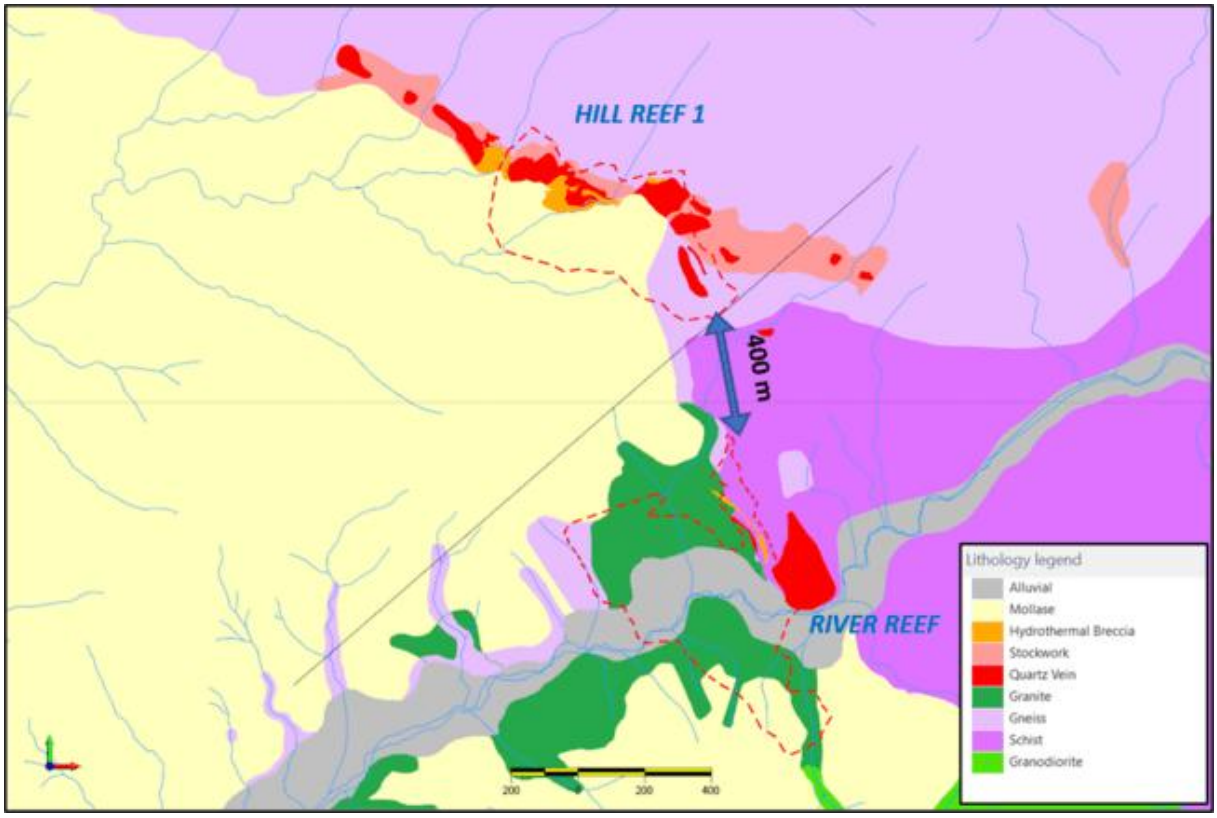

Figure 6. Poboya River Reef and Hill Reef 1 mineralization outline

The average concentration of each element was plotted against elevation to evaluate variations in metal distribution with depth. Precious and base metal concentrations were also projected onto representative geological sections to illustrate their spatial distribution within the mineralized zones. Elevation levels are expressed in meters Relative Level (mRL), representing relative elevations corresponding to meters above sea level.

Additional geological data recorded for each sample include quartz vein textures, quartz vein abundance, sulphide mineral assemblages, and sulphide abundance. Vertical zonation of these geological parameters was evaluated using cross-sections divided into 50 m elevation intervals. For each elevation interval, the dominant geological characteristics were used to examine the relationship between quartz veining, sulphide mineralization, and gold grade as a function of depth.

River Reef and Hill Reef 1 mineralized zones are separated by approximately 400 m in the north–south direction laterally. Based on the latest drilling data, the mineralization does not appear to be directly continuous between River Reef and Hill Reef 1. However, cross-sectional interpretations indicate that the mineralized zones at both River Reef and Hill Reef 1 show vertical continuity.

Vertical Metal Zonation in Cross Section

Quartz veins precipitate from metal-bearing hydrothermal fluids. Within the shallow upflow zones of most geothermal systems, these fluids typically maintain a near-neutral pH. As they interact with host rocks, they produce a stable hydrothermal alteration assemblage characterized by quartz, albite, adularia, illite and/or smectite, chlorite, zeolites, various calc-silicates, calcite, pyrite, and base-metal sulfides.

The analysis of precious and base metals was conducted using geochemical data from the main vein zone. Statistical analyses were performed by examining the distribution of geochemical data at 50 m elevation intervals, ranging from –100 mRL to 600 mRL. The resulting dataset was then plotted along the major structures of the main vein at their respective elevation levels to identify geochemical vectors, particularly for Au, Ag, Cu, Pb, and Zn.

Gold mineralization at Poboya extends vertically from an elevation of –100 mRL to approximately 450 mRL at the surface within the River Reef, and continues from 450 mRL to 650 mRL, where it is exposed along the ridge as Hill Reef 1. With a gentle vein plunge of approximately 30–35°, the vertical downdip extension of the main mineralized veins reaches about 700 m in the River Reef and 450 m in Hill Reef 1.

The vertical zonation of the River Reef shows a progressive increase in average gold grade from the surface downward at 50 m elevation intervals. The highest gold grades occur between 50 and 100 mRL, reaching an average of approximately 10 g/t Au, which is interpreted as the boiling zone. Gold grades decrease again at greater depths below this interval. In contrast, the vertical zonation of Hill Reef 1 is strongly influenced by oxidation processes, resulting in a slight increase in gold grades at higher elevations. However, gold grades at Hill Reef 1 generally remain around 1 g/t Au. Gold mineralization is also associated with the presence of silver, although silver grades are relatively low, with an Au:Ag ratio of approximately 1:2.

Gold mineralization in both the River Reef and Hill Reef 1 is associated with low base-metal (Cu–Pb–Zn) concentrations, generally <100 ppm at all elevation levels. This contrasts with other epithermal deposits, such as the Permata deposit, Mt. Muro, where Cu–Pb–Zn concentrations exceed 200 ppm throughout the vertical profile (Wurst, 2004), and the Pongkor deposit, where average Cu–Pb–Zn concentrations are generally <100 ppm but increase significantly to >1,000 ppm within the main high-grade mineralization zone (Basuki, 1994., Warmada, 2003).

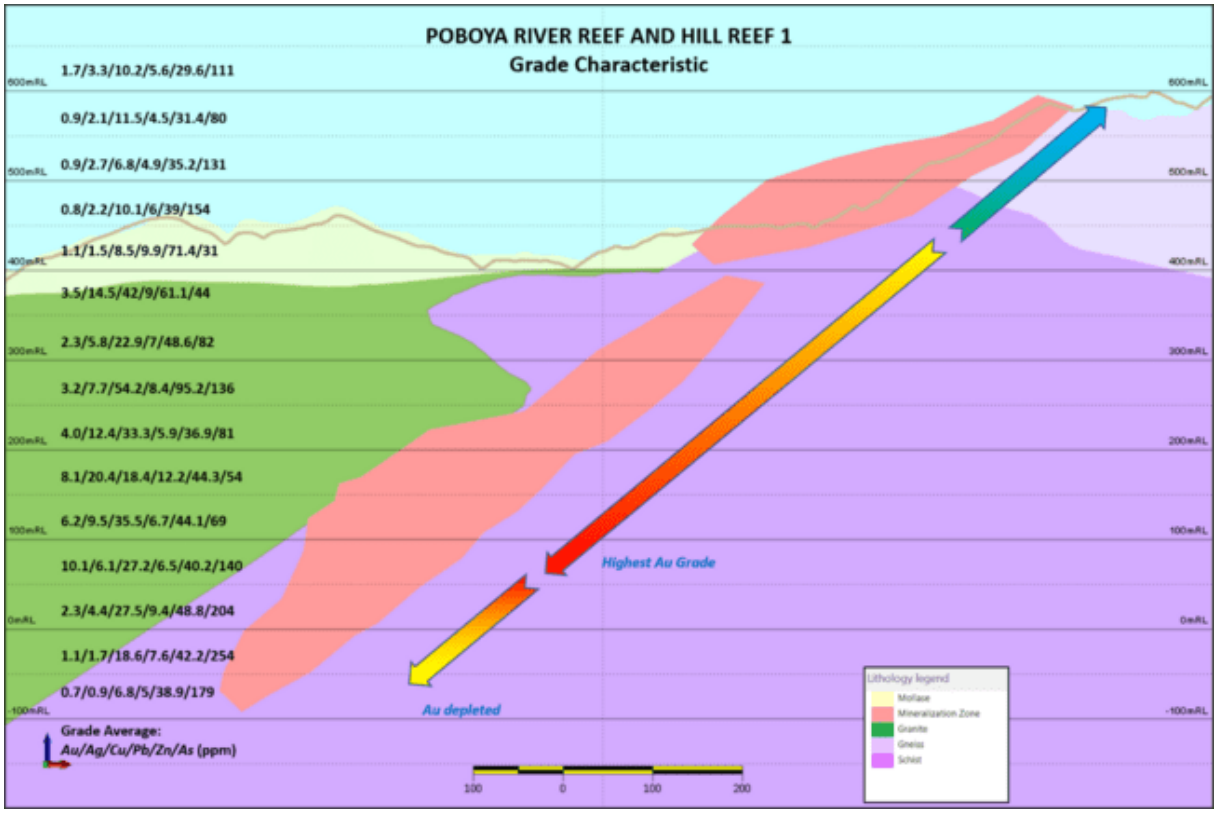

Figure 7. River Reef and Hill Reef 1 grade characteristic over elevation level

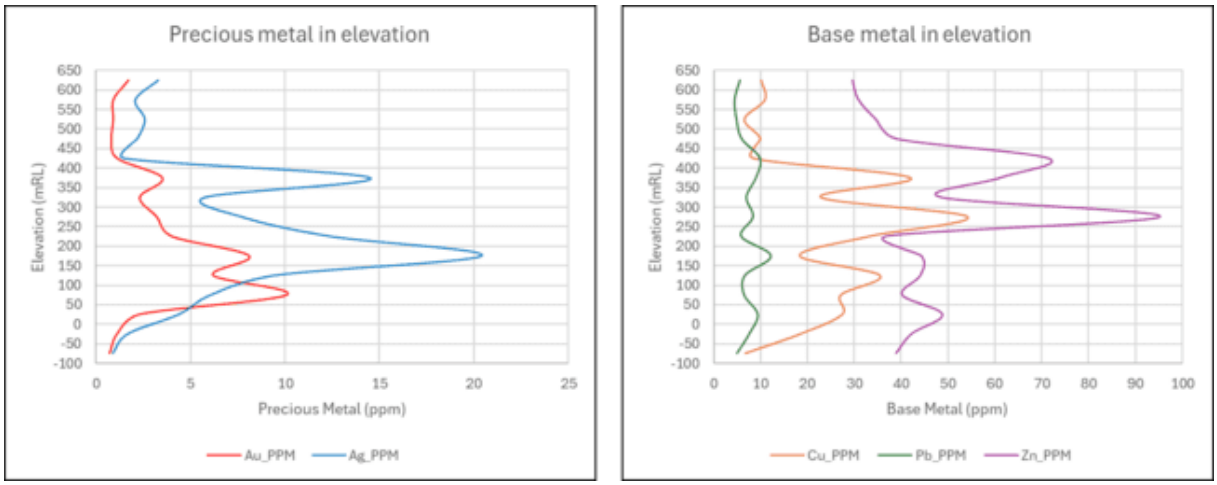

Figure 8. Vertical zonation of Au, Ag, Cu, Pb and Zn in Poboya

The vertical zonation observed at Poboya does not show geochemical vectoring toward elevated base-metal concentrations below the interpreted boiling level. This characteristic indicates that the Poboya mineralization represents a gold–silver deposit with only minor base-metal association. Base-metal concentrations at Poboya are not closely associated with the gold mineralization, as the average values at each elevation remain within the range of natural background abundances for base metals in the continental crust.

Table 2 Summary of Metal Values in Elevation Level

Elevation (mRL)	Au (ppm)	Ag (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	As (ppm)	Sb (ppm)	Mo (ppm)	Hg (ppm)
600-650	1.7	3.3	10.2	5.6	29.6	111	3.5	2	0.4
550-600	0.9	2.1	11	4.5	30.9	79	4.3	1.5	1.5
500-550	0.9	2.6	6.6	4.9	34.6	133	6.2	1.5	0.7
450-500	0.8	2.2	10	6	39	154	4.5	1.6	0.2
400-450	1.1	1.5	8.5	9.9	71.4	31.0	4.6	1.3	1.6
350-400	3.5	14.5	42.0	9.0	61.1	44.0	6.8	1.6	0.8
300-350	2.3	5.8	22.9	7.0	48.6	82.0	5.9	1.9	0.1
250-300	3.2	7.7	54.2	8.4	95.2	136.0	14.6	2.2	0.2
200-250	4.0	12.4	33.3	5.9	36.9	81.0	7.2	1.4	0.1
150-200	8.1	20.4	18.4	12.2	44.3	54.0	6.0	2.3	0.0
100-150	6.2	9.5	35.5	6.7	44.1	69.0	4.5	2.4	0.0
50-100	10.1	6.1	27.2	6.5	40.2	140.0	5.1	2.0	0.0
0-50	2.3	4.4	27.5	9.4	48.8	204.0	6.8	2.1	0.0
(-50)-0	1.1	1.7	18.6	7.6	42.2	254.0	8.0	2.3	0.1
(-100)-(-50)	0.7	0.9	6.8	5.0	38.9	179.0	3.1	1.9	0.0

The average crustal abundances of the major base metals are approximately 60 ppm for Cu, 14 ppm for Pb, and 70 ppm for Zn (Lide, 2005). In comparison, the mean concentrations at Poboya are 23.8 ppm Cu, 10.1 ppm Pb, and 50.3 ppm Zn, all of which are below the corresponding average crustal abundances. These results indicate that gold and silver mineralization at Poboya was not accompanied by significant enrichment of base metals at any elevation level.

Table 3 Abundance of Element in Poboya Relative to Earth Crust

Description	Au (ppm)	Ag (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	As (ppm)	Sb (ppm)	Mo (ppm)	Hg (ppm)
Average in Poboya	3.4	7.3	20.8	9.5	50.1	112.5	6.3	1.9	0.2
Average in Crust	0.004	0.08	60.00	14.00	70.00	1.80	0.20	1.20	0.09

Lateral Metal Zonation in Longitudinal Section

Precious metal (gold and silver) grades were plotted on longitudinal sections to evaluate their lateral and vertical distribution along the main River Reef and Hill Reef 1 deposits. The metal distribution displayed on these sections indicates that both lithology and structural features exert significant controls on the distribution of Au and Ag mineralization at Poboya.

The highest Au and Ag grades at Poboya are found within the main northwest–southeast-trending structure of the River Reef, with the mineralization plunging toward the southeast. In contrast, Au and Ag grades are generally lower in the Hill Reef 1 area. Base-metal concentrations at Poboya remain consistently low from depth to the surface, with Cu, Pb, and Zn concentrations generally below 100 ppm. This is consistent with geological logging observations, which indicate that sulphide mineralization is very weak, averaging less than 0.5% volume sulphides.

The major structures at Poboya trend approximately west–northwest to east-southeast within Hill Reef 1, and changing to a northwest–southeast orientation in the River Reef. The structures at Hill Reef 1 host the main vein zone characterized by low gold grades, dominated

by grades of 0.5–1 g/t Au, with only limited occurrences of moderate grades (1–3 g/t Au). In contrast, the northwest–southeast-trending structures at River Reef host the main vein zone with significantly higher gold grades, dominated by moderate grades (1–3 g/t Au) that surround high-grade zones exceeding 5 g/t Au. A similar lateral distribution pattern is observed for Ag. The structures at Hill Reef 1 are characterized by low silver grades, dominated by 1–2 g/t Ag, with minor occurrences of moderate grades (2–5 g/t Ag). In contrast, the northwest–southeast-trending structures at River Reef host the main vein zone with higher silver grades, dominated by 2–5 g/t Ag, enclosing high-grade zones exceeding 10 g/t Ag.

Low Au and Ag grades occur near the surface between 400 and 650 mRL within Hill Reef 1, extending along the northwest–southeast trend. Gold mineralization in Hill Reef 1 is generally characterized by low-grade mineralization (0.5–1 g/t Au), enclosing only limited zones of moderate-grade mineralization (1–3 g/t Au). Silver mineralization shows a similar distribution pattern, consisting predominantly of low grades (1–2 g/t Ag) with localized zones of moderate grades (2–5 g/t Ag). High-grade mineralization (>5 g/t Au) is concentrated within the River Reef, primarily between 200 mRL and 0 mRL. Gold and silver mineralization display similar spatial distributions, with both plunging toward the southeast along the prospect.

Elevated Au and Ag grades show a well-defined spatial distribution, with most high-grade mineralization concentrated between 0 and 200 mRL. The plunge direction of several ore shoots coincides with the plunge of the major structural zones and the contact between the schist and gneiss, indicating that both structural architecture and lithological contacts exert important controls on mineralization. The high Au grades observed between 50 and 200 mRL are also associated with other geological evidence indicating the occurrence of boiling within the hydrothermal system. In addition, bonanza-grade gold mineralization is locally present above 200 mRL, particularly at the intersections of northwest- and north-northwest-trending structures.

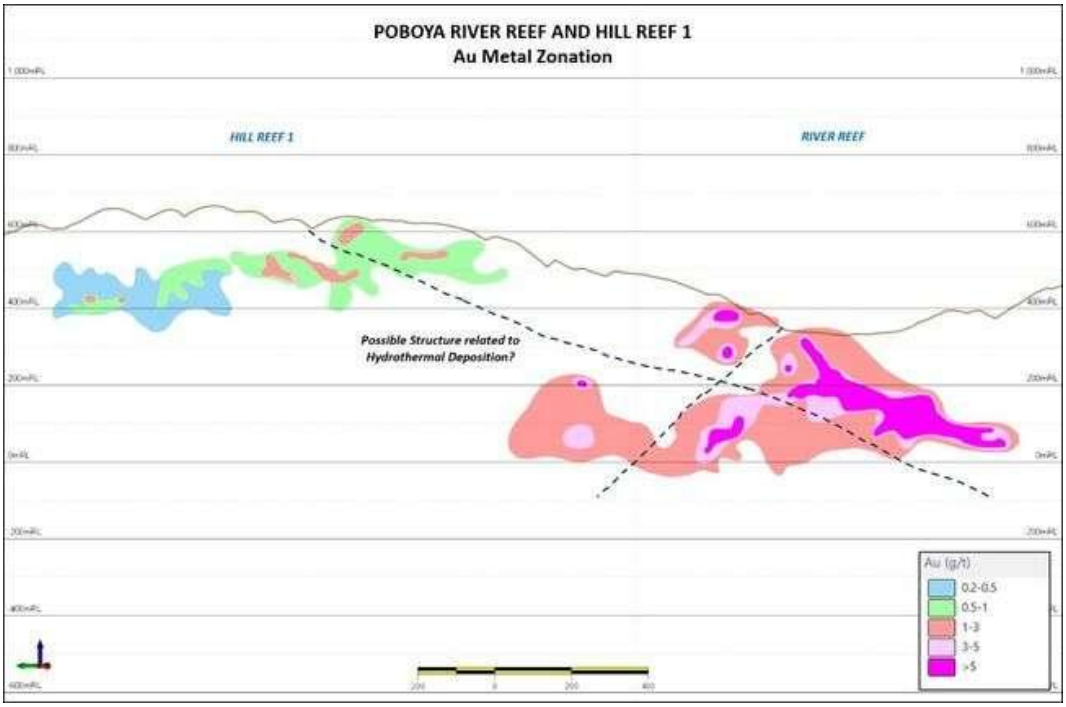

Figure 9. Au metal zonation in longitudinal section

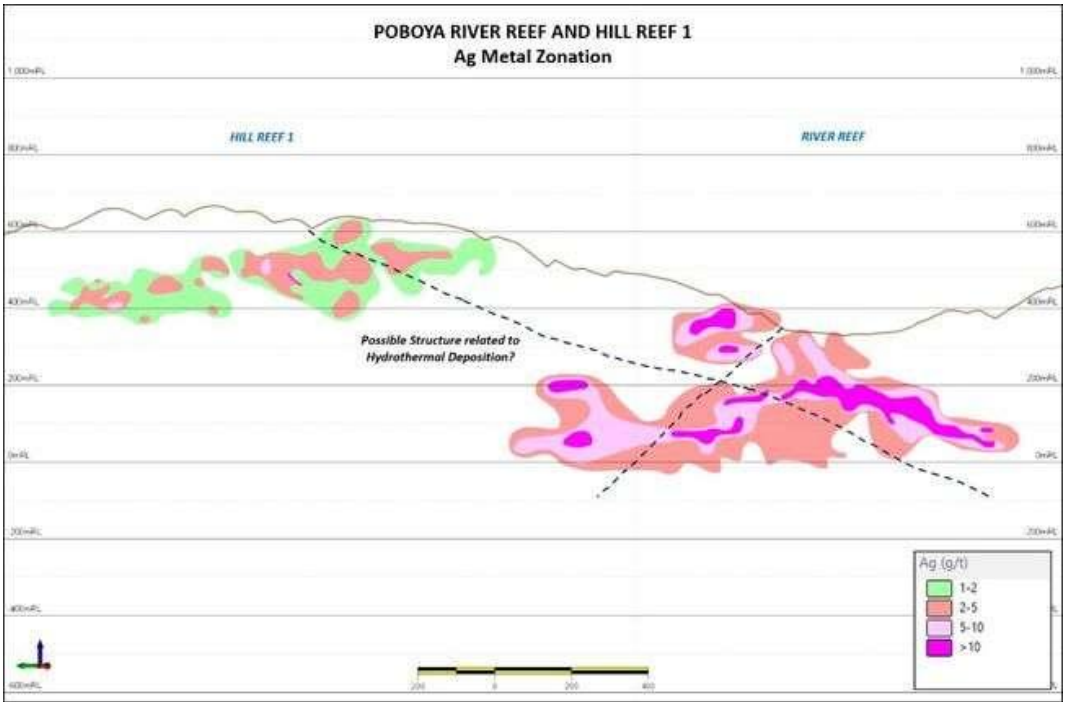

Figure 10. Ag metal zonation in longitudinal section

Vein Texture Zonation

Quartz is the dominant gangue mineral and is commonly the only mineral phase deposited throughout the lifespan of the hydrothermal system. Consequently, quartz characteristics—including morphology, crystal structure, chemical composition, and physicochemical properties—may reflect variations in hydrothermal conditions during vein growth, including those favourable for gold mineralization (Dong, et all, 1995). A descriptive classification of quartz vein textures was developed based on a review of the literature and detailed examination of numerous epithermal vein samples from Poboya. Nine main vein textures were identified and used as the basis for describing the Poboya mineralization system: chalcedonic, crystalline, crustiform, colloform, crustiform-colloform, bladed/lattice calcite-replacement, banded, massive, and vuggy.

The analysis was conducted by examining the statistical distribution of quartz vein textures at 50 m elevation intervals, from –100 mRL to 600 mRL. The resulting dataset was then plotted along the major structures of the main vein at their respective elevation levels to identify the spatial distribution of each quartz texture and evaluate its relationship with gold grades. Certain quartz vein textures can be used as indicators of boiling within epithermal environments. Furthermore, a positive correlation exists between gold mineralization and specific quartz textures, suggesting that quartz precipitation acted as a precursor to, or occurred contemporaneously with, gold deposition during the evolution of the hydrothermal system.

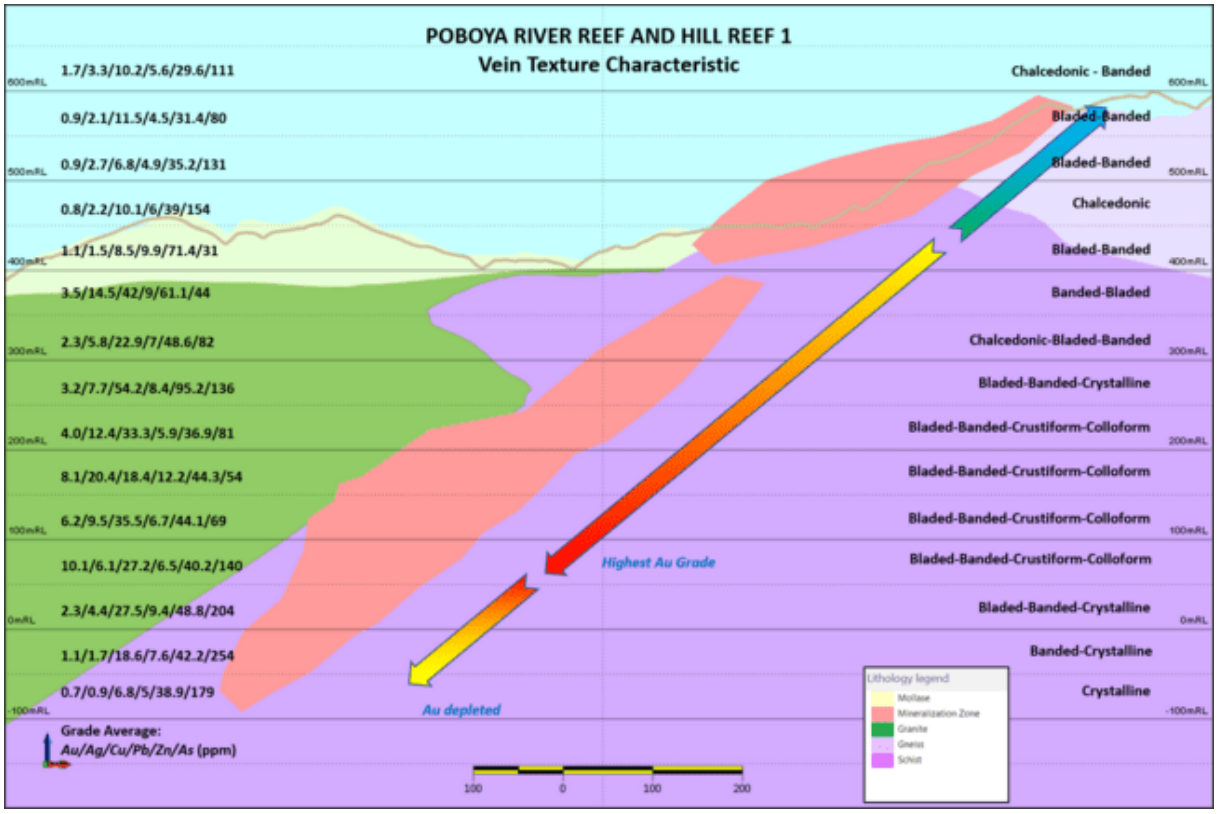

Figure 11. Vein Texture zonation in vertical section

An analysis of the vertical distribution of quartz vein textures was also conducted for the River Reef and Hill Reef 1 deposits. Mineralization in the upper part of the system, between 600 and 400 mRL, is predominantly characterized by chalcedonic and bladed quartz textures. These textures are particularly well preserved because most of the material is exposed at the surface and has undergone oxidation. Between 400 and 200 mRL, the dominant vein textures transition toward bladed and banded quartz. Colloform and crustiform quartz textures become increasingly abundant within high-grade mineralized zones between 200 and 50 mRL. This interval is interpreted as the boiling zone, where the development of these textures is closely associated with high-grade gold mineralization. At deeper levels, from 50 to –50 mRL, the dominant quartz texture gradually changes with the appearance of crystalline quartz, indicating a deeper level of the hydrothermal system where gold grades begin to decrease. Overall, bladed quartz occurs across nearly all elevation levels, suggesting that the boiling level migrated vertically during the evolution of the River Reef hydrothermal system.

Association of Gold Mineralization with Quartz and Sulphide

Association of Gold Grade with Quartz Abundance and Quartz Vein Textures

Gold mineralization at Poboya is strongly associated with the presence of quartz veins. For each sample submitted to the laboratory, quartz abundance data were collected to evaluate the influence of quartz abundance on the resulting assay grades. The datasets used include quartz abundance (%) and the dominant quartz texture. Both datasets were obtained from visual logging conducted by the geological team. The analysis was performed by plotting quartz abundance against gold grade and evaluating the relationship between these parameters. The quartz abundance plots show that Au grades increase with increasing quartz abundance. Samples with quartz abundance of <0.5% generally contain gold grades of <1 g/t Au, whereas quartz abundance between 0.5 and 10% corresponds to gold grades of approximately 1–2 g/t

Au. Furthermore, quartz abundance between 10 and 40% is associated with gold grades ranging from 2–5 g/t Au, while quartz abundance of >40% corresponds to gold grades exceeding 5 g/t Au. The plot indicates that samples with quartz abundance of <40% generally yield gold grades below the average Au grade of 3.7 g/t, whereas quartz abundance above 40% results in a significant increase in gold grade. These observations demonstrate that gold mineralization at Poboya is strongly associated with quartz abundance within the mineralized zones.

An analysis of the relationship between quartz textures and gold grades was also conducted by plotting quartz texture data against Au grades. The resulting plot shows that Au grades increase with changes in the dominant quartz textures. Chalcedonic and crystalline quartz textures are associated with gold grades of up to 2 g/t Au, whereas vuggy quartz textures correspond to gold grades of up to 3 g/t Au. Furthermore, banded and bladed quartz textures are associated with gold grades of approximately 6 g/t Au, while crustiform, colloform, and crustiform-colloform quartz textures are associated with gold grades exceeding 6 g/t Au. The plot demonstrates that variations in dominant quartz textures correspond to changes in the depth distribution of mineralization and are associated with significant variations in gold grades. This quartz texture zonation is consistent with the classical low-sulfidation epithermal model of Buchanan 1981 (Imawan, 2024), which illustrates the relationship between quartz vein textures and metal deposition.

A defining characteristic of the Poboya hydrothermal system is the widespread occurrence of bladed quartz textures across all observed elevations. This extensive vertical distribution indicates significant migration of the boiling horizon during the evolution of the system. The dynamic fluctuation of the boiling zones driven by shifts in the paleo-water table or episodic pressure changes played a critical role in promoting phase separation and the subsequent precipitation and enrichment of gold mineralization.

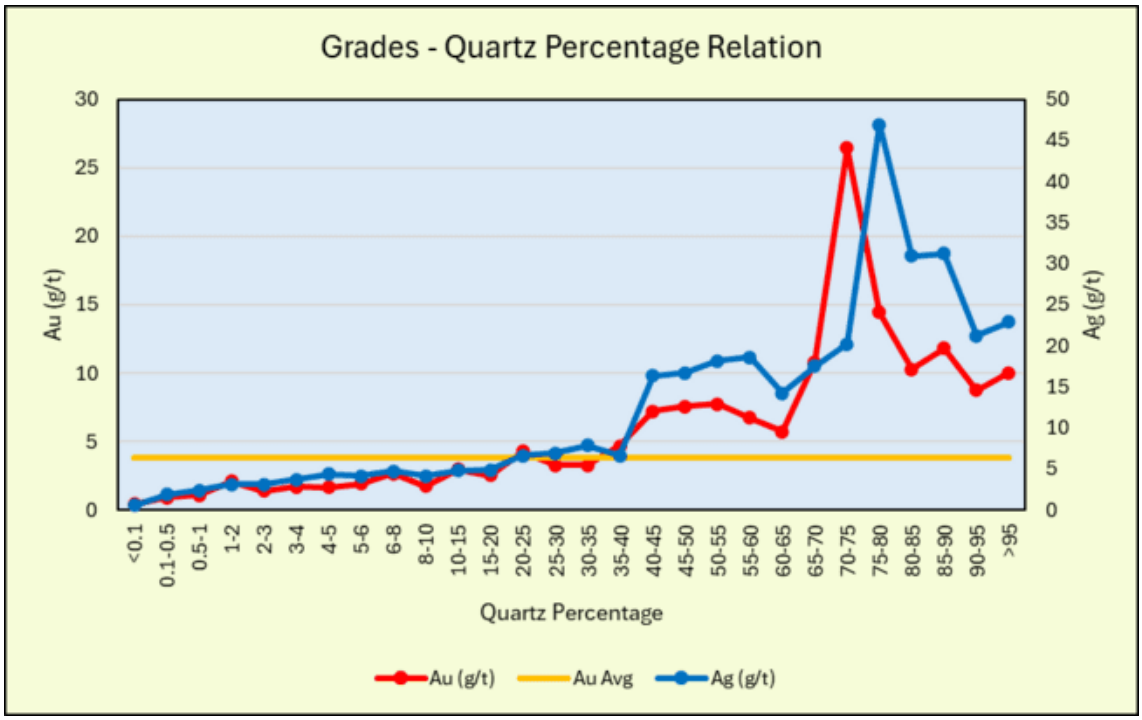

Figure 12. Relationship Between Au Grade and Quartz Abundance

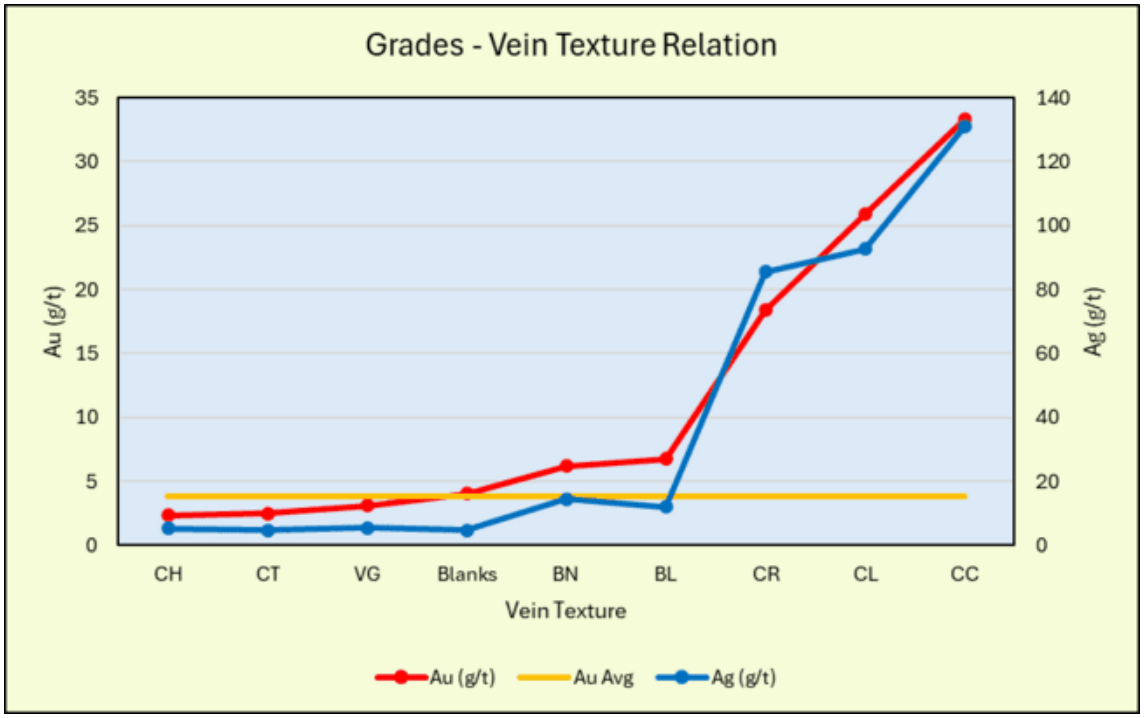

Figure 13. Relationship Between Au Grade and Quartz Texture

Association of Gold Grade with Sulphide Abundance and Sulphide Mineral

As discussed in the previous section, gold mineralization at Poboya is strongly associated with the presence of quartz veins and is characterized by relatively low sulphide content. This analysis was conducted to evaluate the degree of association between gold grade and sulphide abundance within the mineralized zones. The datasets used include sulphide abundance (%) and the dominant sulphide mineral species. Both datasets were obtained from visual logging conducted by the geological team.

The analysis was performed by plotting sulphide abundance against gold grade and evaluating the relationship between these parameters. The sulphide abundance plot indicates that Au grades tend to decrease with increasing sulphide abundance. Samples with sulphide abundance of <0.3% are associated with relatively high gold grades of approximately 3–5 g/t Au, whereas sulphide abundance between 0.4 and 2% corresponds to gold grades of approximately 2–3 g/t Au. Furthermore, sulphide abundance between 3 and 5% is associated with gold grades of approximately 1 g/t Au, while sulphide abundance of >5% corresponds to gold grades of <1 g/t Au. The plot shows that samples with sulphide abundance >0.7% generally yield gold grades below the average Au grade of 3.7 g/t, whereas sulphide abundance <0.7% is associated with gold grades above the average value. These results indicate that gold mineralization at Poboya is not positively correlated with total sulphide abundance, although specific sulphide and sulphosalt phases may be locally associated with high-grade Au.

An analysis of the relationship between mineral species and gold grade was also conducted by plotting mineral types against Au grades. The minerals observed at Poboya include oxide minerals such as limonite, hematite, and manganese oxides, while the sulphide minerals consist of pyrite, chalcopyrite, and grey/black sulphide minerals. Based on the analysis results, gold associated with limonite and hematite is characterized by grades of approximately 0.8 g/t Au, whereas gold associated with chalcopyrite reaches grades of up to 2.5 g/t Au. Gold associated with pyrite shows grades of approximately 3.7 g/t Au, which

corresponds to the average gold grade at Poboya. High-grade gold mineralization is associated with manganese minerals and visually logged grey/black sulphide-like minerals, with grades exceeding 10 g/t Au; further mineralogical confirmation by mineragraphy, SEM-EDS, or EPMA is recommended for these phases.

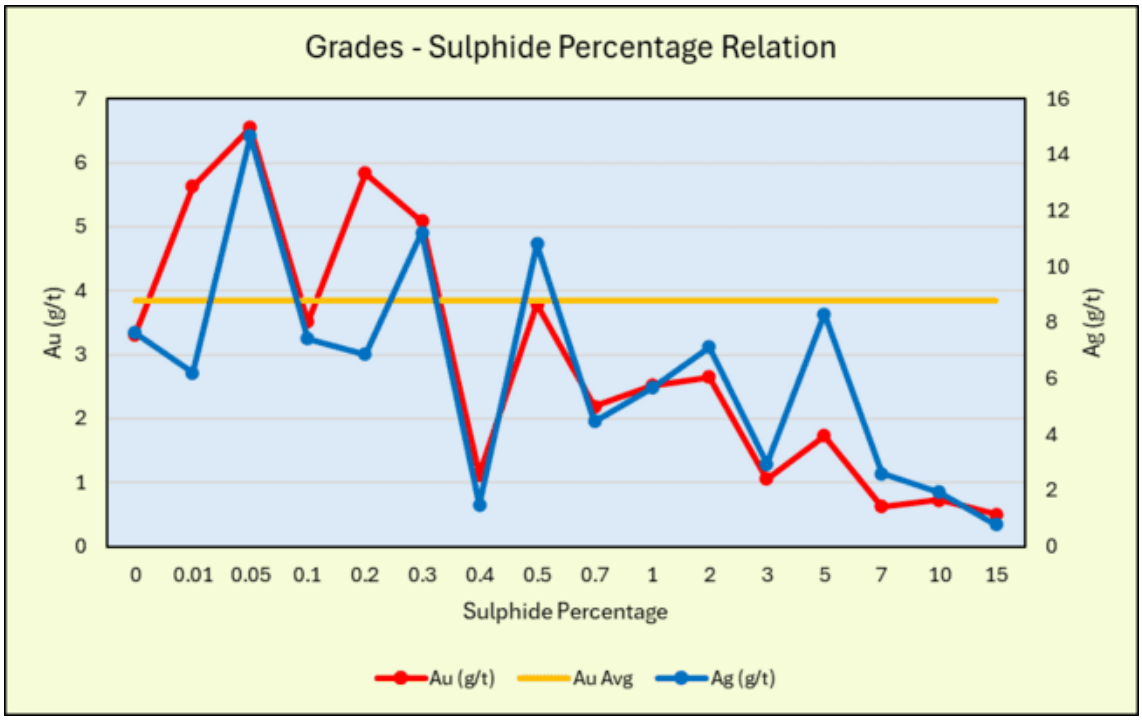

Figure 14. Relationship Between Au Grade and Sulphide Abundance

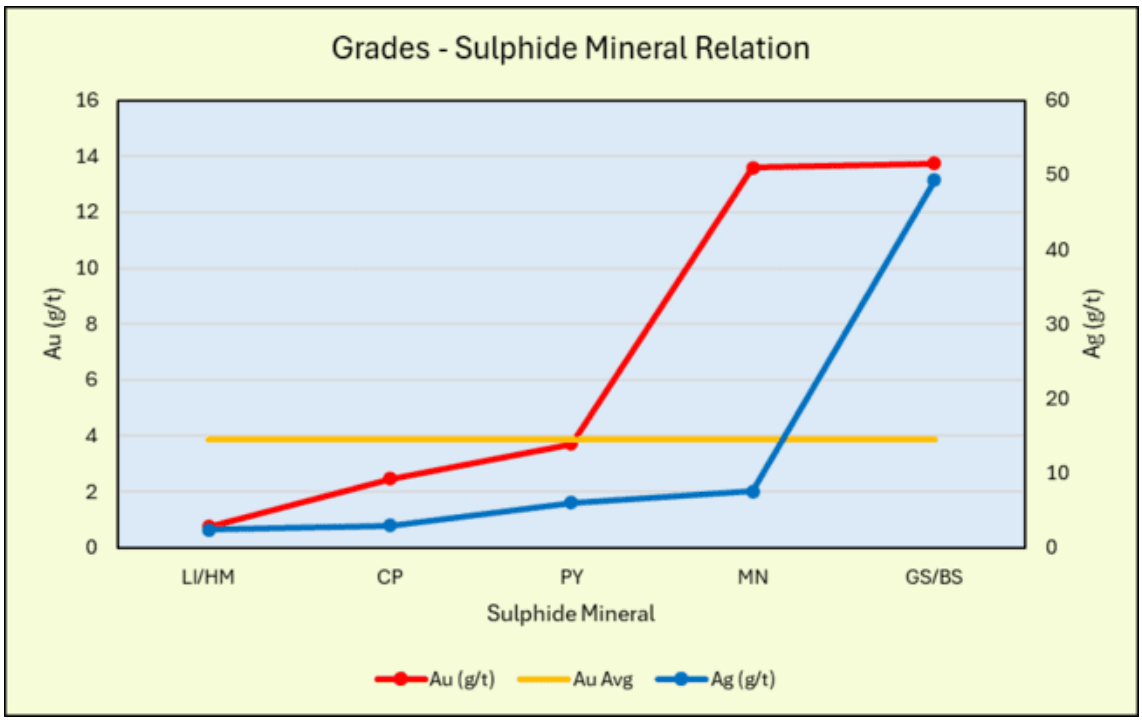

Figure 15. Relationship Between Au Grade and Sulphide Mineral

Pyrite is the dominant sulphide mineral identified at Poboya, although the overall sulphide abundance is relatively low. The presence of pyrite was recorded in more than 10,000 visual logging observations, with individual occurrences generally showing low sulphide abundance.

Au grammeter

Au gram-meter is a simple exploration method that combines gold grade (g/t) and drill-hole intercept thickness (m) into a single value, expressed as gram-meters. This method is widely applied in exploration, particularly in low-sulfidation epithermal deposits controlled by quartz veins (Angeles et all, 2002). One of the main advantages of the gram-meter concept is its ability to provide a balanced evaluation of two critical factors in gold exploration: mineralization grade and thickness. A thin interval with high-grade mineralization may have equivalent potential to a thick interval with lower grades. This approach is useful for comparing grade–thickness distribution within structural corridors characterized by pinch-and-swell geometries. The Au gram-meter analysis was conducted using geochemical data from drill-hole intercepts, including gold grade and thickness within the main vein zone. The thickness values used represent the true thicknesses converted from the original drill intercepts. Based on the Au metal zonation, Hill Reef 1 show lower gold grades compared with the River Reef. Hill Reef 1 forms a main vein zone characterized by low Au grades, dominated by low-grade mineralization (0.5–1 g/t Au), whereas the upper part of River Reef is dominated by moderate-grade mineralization (1–3 g/t Au). However, the Au gram-meter analysis indicates that the Hill Reef 1 mineralized zone still has significant geological potential due to its relatively thick mineralized intervals.

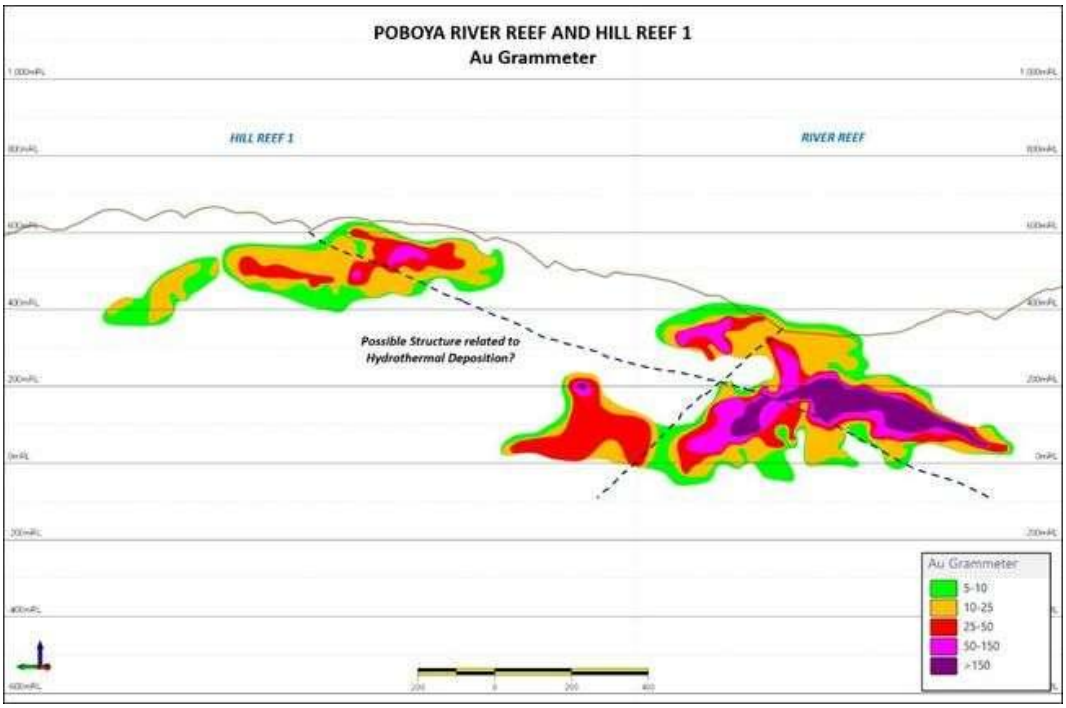

Figure 16. Au gram-meter metal zonation in longitudinal section

The Au gram-meter distribution in Hill Reef 1 is comparable to that of the upper River Reef, with average values ranging from 10–25 Au gram-meters. This demonstrates that lower-grade mineralization with greater thickness can have equivalent potential to higher-grade

mineralization with moderate or even limited thickness. The Au gram-meter zonation in River Reef and Hill Reef 1 indicates that the hydrothermal fluids maintained relatively similar metal-bearing capacities within different structural opening corridors. Hill Reef 1 is characterized by lower grades with thicker intercepts, averaging approximately 24 m, whereas River Reef shows moderate grades with average intercept thicknesses of approximately 15 m in the upper zone and 24 m in the lower zone. This hydrothermal fluid distribution concept based on Au gram-meter analysis is highly useful for defining future exploration targets, as it integrates both grade and thickness characteristics to evaluate mineralization potential.

Discussion

The Poboya gold deposit is recognized as a low-sulfidation epithermal Au–Ag deposit hosted within metamorphic rocks. Gold mineralization is characterized by an Au:Ag ratio of approximately 1:2, with low base-metal concentrations (Cu–Pb–Zn <100 ppm), and is associated with quartz veins showing bladed, chalcedonic, colloform, and crustiform textures. These characteristics are further supported by mineragraphic data, which indicate a strong association between gold mineralization and quartz. From the 193 gold observations, approximately 80% of gold occurs within quartz–calcite or platy calcite veins, 14% occurs within calcite, and the remainder occurs in association with pyrite and quartz, either within veins or within the breccia matrix. The gold grains are extremely fine-grained, with an average size of approximately 10 microns, while the largest observed grain reaches approximately 50 microns.

The vertical mineralization zonation from top to bottom consists of a low-grade vein and stockwork zone (Hill Reef 1), moderate-grade splay vein and stockwork zone (upper River Reef), and high-grade main vein and splay vein zone (lower River Reef). The low-grade mineralization zone at Poboya occurs between 650 and 450 mRL, with average gold grades of approximately 1 g/t Au and is located within the Hill Reef 1 prospect. This mineralization zone is associated with chalcedonic, banded, and bladed quartz textures. The moderate-grade mineralization zone occurs between 450 and 200 mRL, with gold grades ranging from approximately 1 to 3 g/t Au and is located within the upper River Reef prospect. This zone remains associated with chalcedonic, banded, and bladed quartz textures. Crystalline and crustiform quartz textures begin to appear between 300 and 200 mRL, accompanied by an increase in gold grades to approximately 3–4 g/t Au. The very high-grade mineralization zone at Poboya occurs between 200 and 50 mRL, with average gold grades exceeding 5 g/t Au. Between 200 and 150 mRL, high-grade mineralization averages 8.1 g/t Au and 20.4 g/t Ag. Between 150 and 100 mRL, high-grade mineralization averages 6.2 g/t Au and 9.5 g/t Ag. The highest-grade zone occurs between 100 and 50 mRL, with average grades of 10.1 g/t Au and 6.1 g/t Ag.

This high-grade mineralization zone is associated with bladed and banded quartz textures, together with the development of crustiform–colloform textures, indicating a boiling mechanism during gold deposition. The hydrothermal fluids at Poboya are further constrained by low salinities of approximately 0.3–0.7 wt.% NaCl equivalent and homogenization temperatures ranging from 200 to 250°C. Fluid inclusion homogenization temperatures indicate that mineralization formed under epithermal conditions.

Gold mineralization at Poboya occurs within schist, feldspar porphyroblast schist, gneiss, and granite, where the metamorphic rocks represent part of the Palu Metamorphic Complex. These host rocks are crosscut by quartz vein mineralization with a relatively NW–SE structural orientation and a gentle dip of approximately 30°, bounded by major faults beneath the quartz-bearing zone. The occurrence of mineralized veins within fault zone on metamorphic rocks, together with their spatial association with the deep-seated Palu–Koro Fault, suggests that this

regional fault acted as the principal conduit for hydrothermal fluid migration. The quartz vein mineralization reaches average thicknesses of approximately 24 m in the deeper River Reef, 14 m in the upper River Reef, and 24 m in Hill Reef 1. These variations in thickness reflect pinch-and-swell geometries associated with structural openings during quartz vein formation.
Fluid redistribution within hydrothermal systems at depth in the crust is governed largely by hydraulic gradients between upstream fluid reservoirs and the downstream regions of permeable networks of active faults, shear zones, and related structures that drain reservoirs. Flow focusing occurs wherever networks of active, high-permeability shear zones, faults, or other permeable structures, penetrate pressurized fluid reservoirs. These structures drain reservoirs and provide pathways for fluid redistribution to higher crustal levels. At the deposit scale, in fracture-controlled hydrothermal systems, the highest fluid flux occurs where theapertures, densities, and connectivities of fractures are greatest (Cox, 2005).

The host rocks of the Poboya mineralization system are dominated by metamorphic and plutonic rocks. Alteration, vein formation, brecciation, and mineralization likely evolved within a hydrothermal system driven by a non-volcanic heat source. These systems typically form during rapid tectonic exhumation within extensional or trans-tensional regimes, where deep crustal rocks are rapidly unroofed to shallow crustal levels. It is interpreted that hydrothermal fluid-flow is strictly structurally controlled; episodic fault kinematics trigger abrupt pressure fluctuations, continuously modifying fluid pathways and hydrothermal circulation patterns.

Conclusions

Au–Ag mineralization in Poboya project exhibits systematic vertical zonation, with Au grades increasing toward the deeper parts of the mineralization system, while base-metal concentrations remain consistently low. This zonation is observed from Hill Reef 1 through the upper and lower River Reef and provides a clear vertical distribution pattern for precious-metal mineralization. Gold is predominantly associated with quartz–calcite and platy-calcite veins. Textural variations in veins correlate with variations in mineralization, with chalcedonic, bladed, and banded textures dominating the shallower and low to moderate-grade zones, while crystalline and crustiform–colloform textures become more prominent toward the higher-grade mineralization.
The combined distribution of metal zonation, vein textures, quartz abundance, structural position, and Au gram-meter values provides practical geological indicators for deeper and lateral exploration. The vertical transition in vein textures and the associated increase in Au grade provide a useful vector toward higher-grade mineralization, while Au gram-meter values provide an integrated measure for evaluating the relative significance of mineralized intervals.

Acknowledgements

The authors thank the management and staff of PT Bumi Resources Minerals and PT Citra Palu Minerals for supporting the fieldwork and providing all the data required by this research. The authors would like to express sincere gratitude to all geologists in Palu for their valuable assistance, insightful discussions, and generous sharing of knowledge throughout this study.

References

AMC, Poboya Mining Prefeasibility Study 2024 PT Citra Palu Minerals, West Perth, Australia, Report No 0223145, 2024.

Angeles, C.A, Prihatmoko, S. and Walker, J.S., Geology and Alteration-Mineralization Characteristics of the Cibaliung Epithermal Gold Deposit, Banten, Indonesia, Resources geology, Volume 52, No 4, p329-339, 2002.

Basuki, A., Sumanagara, D.A. and Sinambela, D., The Gunung Pongkor gold-silver deposit, West Java, Indonesia, Journal of Geochemical Exploration 50, p371-391, 1994.

Calvert, S.J. and Hall, R., Cenozoic evolution of the Lariang and Karama regions, North Makassar Basin, western Sulawesi, Indonesia, Petroleum Geoscience, Volume 13 p353-368, Geological Society of London, 2007.

Cox, S.F, Coupling between Deformation, Fluid Pressures, and Fluid Flow in Ore-Producing Hydrothermal Systems at Depth in the Crust, Economic Geology 100th Anniversary Volume, p39–75, 2005.

Corbett, G.J. and Leach, T.M, Southwest Pacific Rim Gold-Copper Systems: Structure, Alteration and Mineralization, Short Course Manual, Corbett Geological Services - Terry Leach and Co, 1997

Dong, G., Morrison, G. and Jaireth, S., Quartz Texture in Epithermal Vein, Queensland – Classification, Origin and Implication, Economic Geology, Volume 90, p1841-1856, 1995.

Geoservices, CSAMT Survey at Block I, Poboya Village, Mantikulore District, Palu Regency, Central Sulawesi Province., Report No: 2024/0901/EXP, Geoservices, Palu, Indonesia, 2024.

Hall, R. and Wilson, M.E.J., Neogene sutures in eastern Indonesia, Journal of Asian Earth Sciences 18, p781–808, 2000.

Hawke, M., and Leach, T.M., Petrographic Descriptions, X-ray Diffraction and Fluid Inclusion Analyses and Photographic Study of One Surface and Three Drill core Samples from Sulawesi, Report for PT. Rio Tinto Indonesia, CMS Report No 9505 (Reference 4003/83), CMS New Zealand Ltd, Auckland, New Zealand, 1995.

Imawan, L., Titisari, A.D. and Setiawan, I, Mineralogy and Hydrothermal Fluids Characteristics of the Mekarbakti Low Sulfidation Epithermal Gold Prospect at Garut Regency, West Java, Indonesia, IOP Conf. Series: Earth and Environmental Science 1378, IOP Publishing, 2024.

LAPI ITB, Hasil Pengamatan Mineralogi, Petrografi dan Mineragrafi Sampel Batuan, PT. Citra Palu Minerals, Laboratorium Mineralogi, Mikroskopi Dan Geokimia, Fakultas Teknik Pertambangan Dan Perminyakan, Institut Teknologi Bandung, Bandung, Indonesia, 2021.

Lide, D.R., CRC Handbook of Chemistry and Physics, Internet Version 2005, <http://www.hbcpnetbase.com>, CRC Press, Boca Raton, Florida, 2005

Lindgren, W., Mineral Deposits, Fourth Edition Revised and Reset, Mcgraw-Hill Book Company Inc, New York and London, 1933.

Marten, B.E., Report on a Visit to The Palu Prospect, Central Sulawesi, Indonesia, Rio Tinto Mining and Exploration Limited, Internal Report, Bristol, United Kingdom, 1999.

Maulana, A., Imai, A., Watanabe, K., Van Leeuwen, T., Widodo, S., and Musri., Exhumation and Tectonomagmatic Processes of the Granitoid Rocks from Sulawesi, Indonesia: Constrain from Petrochemistry and Geothermobarometry Study. *Indonesian Journal on Geoscience*, Volume 6 No 2, p.153-174, 2019.

Rivai, T.A., Characteristic of Gold Mineralization at The River Reef Zone, The Poboya Prospect, Centtral Sulawesi, Indonesia, Thesis Master, Kyushu University, Fukuoka, Japan, 2016.

Syafrizal, Rivai T.A, Yonezu K., Kusumanto D., Watanabe K., and Hede ANH., Characteristics of a Low-Sulfidation Epithermal Deposit in the River Reef Zone and the Watuputih Hill, the Poboya Gold Prospect, Central Sulawesi, Indonesia: Host Rocks and Hydrothermal Alteration, www.mdpi.com/journal/minerals, 16 pages, 2017

Van Leeuwen, T.M. and Muhardjo, 2005, Stratigraphy and Tectonic Setting of the Cretaceous and Paleogene Volcanic-Sedimentary Successions in Northwest Sulawesi, Indonesia: Implications for the Cenozoic Evolution of Western and Northern Sulawesi. Journal of Asian Earth Science 25, p481–511, 2005

Van Leeuwen, T.; Allen, C.M.; Kadarusman, A.; Elburg, M.; Michael Palin, J.; Muhardjo; Suwijanto., Petrologic, Isotopic, and Radiometric Age Constraints on the Origin and Tectonic History of the Malino Metamorphic Complex, Nw Sulawesi, Indonesia. Journal of Asian Earth Science 29, p751–777, 2007.

Wajdi, M.F.; Santoso, B.; Kusumanto, D.; Digdowirogo, S., Metamorphic Hosted Low Sulphidation Epithermal Gold System at Poboya, Central Sulawesi: A General Descriptive Review. Majalah Geologi Indonesia, Volume 27, No.2 p131–141, 2012.

Warmada, I.W and Lehmann, B., Polymetallic Sulphides and Sulfosalts of The Pongkor Epithermal Gold–Silver Deposit, West Java, Indonesia, The Canadian Mineralogist, Vol. 41, pp. 185-200, 2003.

White, N.C. and Hedenquist, J., Epithermal Gold Deposits: Styles, Characteristics and Exploration, SEG Newsletter, No 23, p.1, 9-13, 1995.

White, P., Petrology of ten samples from Poboya for PT Citra Palu Minerals, Panda Geoscience Limited, Taupo, New Zealand, 2025

Wurst, T.W., Geology and Genesis of the Permata- Batu Badinding - Hulubai and Kerikil Au-Ag Low Sulfidation Epithermal Deposits, Mt Muro, Kalimantan, Indonesia, Thesis Doctor, University of Tasmania, Tasmania, Australia, 2004.

Yuwono, Y.S., Petrografi Sampel Poboya dan Sintesa Petrogenesisnya, Bandung, Indonesia, 2012.

Zhang, L. and Merchant, R., The Petrology of Four Drillcore samples from The Palu Prospect Central Sulawesi Indonesia, report for PT Rio Tinto Indonesia, TLC Report No 96059 (Reference 14410), Terry Leach & Co, Auckland, New Zealand, 1996.