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## Geochemical correlation of gold placer and indication of Au-Cu-Pb-Zn-Ag mineralization at Parigi Moutong, Central Sulawesi, Indonesia

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## Geochemical correlation of gold placer and indication of Au-Cu-Pb-Zn-Ag mineralization at Parigi Moutong, Central Sulawesi, Indonesia

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**Abstract.** Parigi Moutong area is known as a destination for craftsmen and small-scale gold mining to get gold grains on rock, soil and river deposits. Gold granules were found in two morphological, there are Northern Hills (MNH) - and Morphology of Southern Hills (MSH), both of these morphologies were controlled by geological structures. The morphology of Northern Hills (MNH) is composed by granite, diorite, andesite non-andesite mineralization of sulphide mineralization, the dominance of the composition of gold granules found in river deposits on the soil. The morphology of the South Hills (MSH) spreads to the terrain and beaches composed by granite, andesite, schist, gneiss, molasses, Tinombo Formation, and the dominance of gold granular concentrations found on the soil.

This paper aims to differentiate geochemical characteristics of MNH and MSH on soil and gold grains obtained by panning concentrate method of river deposit and soil, and predicts the types of primary deposits as a source of gold granules. The difference of gold association is related to the type of placer deposit, i.e the fluvial placer in the soil in the form of a residual deposit bag takes the path of weathering transport of andesite mineralization and fluvial tectonic transported zona brecciated. By normal P-P plot normality test knowing that the type of Au deposit correlates strongly with Cu compared to Pb correlated Au, and Cu increases linearly with Pb. Concentration on soil fluvial weathering and changes is higher than in soil fluvial tectonic transported.

The result rotation of the Au, Cu, Pb, Zn matrix components show there are two distributions of strongly correlated variables, namely (1) Au (0.953) -Ag (0.949) and (2) Cu (0.900) -Zn (0.902). Those order correlation is a strong indication of the presence of placer deposit sources as hydrothermal deposits: 1) Au-Cu (2) Au-Zn (3) Cu-Pb and (4) epithermal Au-Ag.

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### I. Introduction

Gold placer deposits are the result of surface processes and related to the evolution of regional geomorphology, and many other models formation [1]. Based on the Geological Map of Toli-Toli Sheet, North Sulawesi [2] the study area is situated in the Metamorphic Rock Complex (km), lake and river deposits (Qa), alluvium and coastal deposits (Qap) which are limited by fault and fold structures. Those geological structures control the variation of mountain morphologies.

**Morphology of the Northern Hills (MNH)** is a systematic mountain range with northeast-southwest distribution direction, composed of granite, diorite, andesite non-andesite mineralization of alteration of sulfide mineralization and soil residue, domination of gold grains in river deposits.



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**Morphology of the Southern Hills (MSH)** trending southwest-northeast-southeast shows a decisive change to hilly morphology to terrain and which is composed by granite, andesite, schist, gneiss, molasses, Tinombo Formation, and concentrations of gold granules dominated in soil containing fragments of these rock (Figure 1).



Figure 1. Geomorphology of mountains, plains and beaches

Fluvial deposits in different morphologies are indicated as residual weathering from Pliocene (Q<sub>tv</sub>) volcanic rock [2]; there are also a granite dyke that formed in the Middle Miocene to Upper Miocene and Paleozoic Metamorphic Rock Complex (Km) [3]. Generally the pattern of dendritic river flow influenced by regional local geological structures and rock contact, the geological structure system is controlled by the major fault of Palu-Koro; the active sinistral fault Palu-Koro with direction northwest-southeast [4].

Placer deposits are accumulations of weathering results of rock containing heavy minerals, transported and deposited with soil and river deposits, during the process of transportation and secondary environments chemical precipitation also occurs [5], [6]. The transportation factor on flatness is the reason for this study because there are differences in the availability of gold grains in soil and river deposits associated with mineral sources and tectonic regional. The analysis of gold grains and geochemical soil aims to determine the differences in the characteristics of Au-Cu-PB-Zn-Ag and the morphology of gold grains obtained from panning concentrate method, and predict primary sediment types as sources of gold grains.

The research (Figure 2) is located in Central Sulawesi Province with the capital city Palu and Parigi Moutong as one of the districts. Physiographically, the area of Palu consists of eastern ridges and western ridges; both are directed north-south and are separated by the Palu Valley (Fossa Sarasina).

Western ridges near Palu, up to more than 200 m high, but in Donggala it declined to the sea level. Eastern ridges up to the peak height of 400-900 m, and connects the mountains in Central Sulawesi with the north arm.

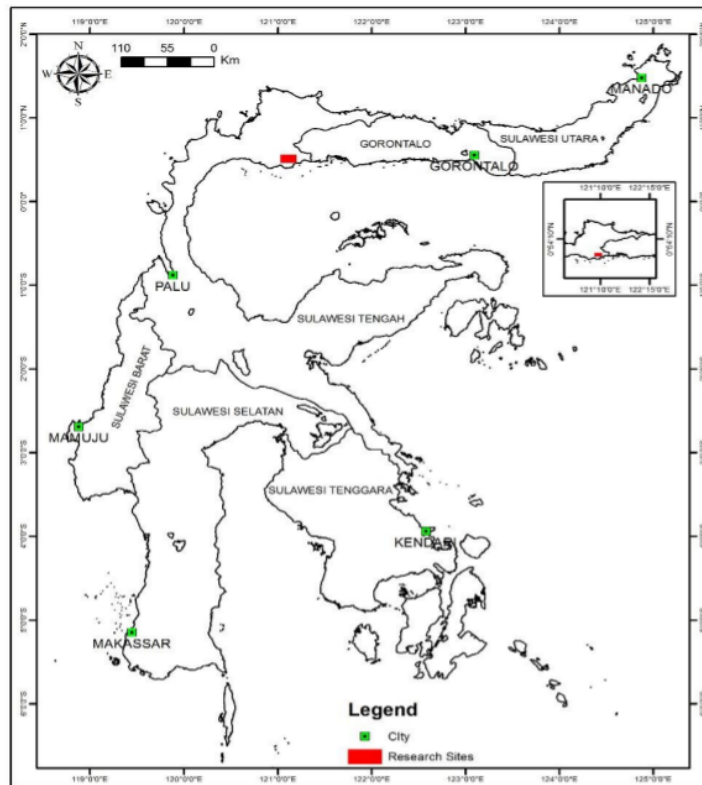


Figure 2. Map of research location

## 2. Stratigraphy

Regional stratigraphy of the study area (Figure 3) :

Metamorphic Rock Complex (Km), green schist (Kmg) [2], [3], basement rock of Sulawesi [4], [7], [8], revealed only in eastern ridges consists of amphibolite schist, schist, gneiss, and marble. There are many schist on the west side, while there are many gneiss and marble on the east side. Then there is dyke diorite, granodiorite breaks through the metamorphic rock complex.

Tinombo Formation (Tt). (shale, sandstone, conglomerate, limestone, radiolarian chert, and volcanic rock), spread to eastern and western ridges. Overlapping unconformably metamorphic rock complex, a folded sequence of volcanic and marine sedimentary rock which have been metamorphosed to greenschist facies [8].

Molasses Celebes (QTms) [3], (composed of reworked older formation, conglomerate, sandstone, mudstone, coral limestone, and marble) spread on the east and west ridges overlapping unconformably Tinombo Formation and metamorphosis rock complex. As post-orogenic siliclastic deposit [9].

Lake and River Deposits (Qa) [2], Alluvium and Coastal Deposition (Qap). Gravel, sand, mud, and coral limestone form in the river, deltas and shallow marine environment.

Intrusion rock (gr, am, di, sy). (diorite, diorite porphyri, microdiorite, and granite-granodiorite with potassium feldspar a phenocryst characteristics) break through the Tinombo Formation and were covered by molasses. Small stocks and dykes cross-cut various lithologies [3].

Based on the appearance of the field on the distribution of rock in MNH and MSH generally controlled by folds and fault structures, it is part of the major Moutong Fault which limits the metamorphic rock complex (Km), granite, and molasses [3]. This structure also has an important role in the thickness of the soil and revealed of the sulfide-gold mineralization rock.

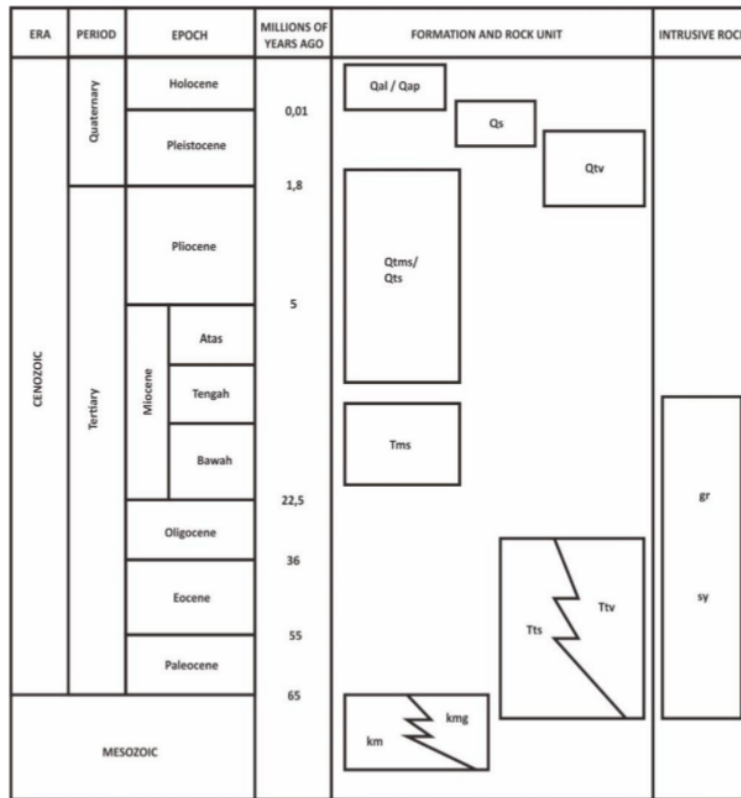


Figure 3. Regional Central Sulawesi stratigraphy

### 3. Methods

Based on field observations, the gold placer was operated by small-scale (artisanal) miners using excavation method or high-pressure water spray (hydraulic) in soil, and then continued by panning fractionating material in the river. This is the reason that this study using more soil sample than river deposit sample.

Samples of alteration andesite outcrops were carried out at MNH (RC1 to RC10), panning test of soil and no gold grains were found, followed by panning test of river deposits in 10 samples (PN1 to 20). In MSH rock samples were taken (RC11 to RC13), soil 41 samples (So1 to So41). Soil samples

were taken in the form of panning samples of 10 samples (So / PN21 to So / PN30) and panning of river deposits by 10 samples (PN31 to PN40) (Figure 4).

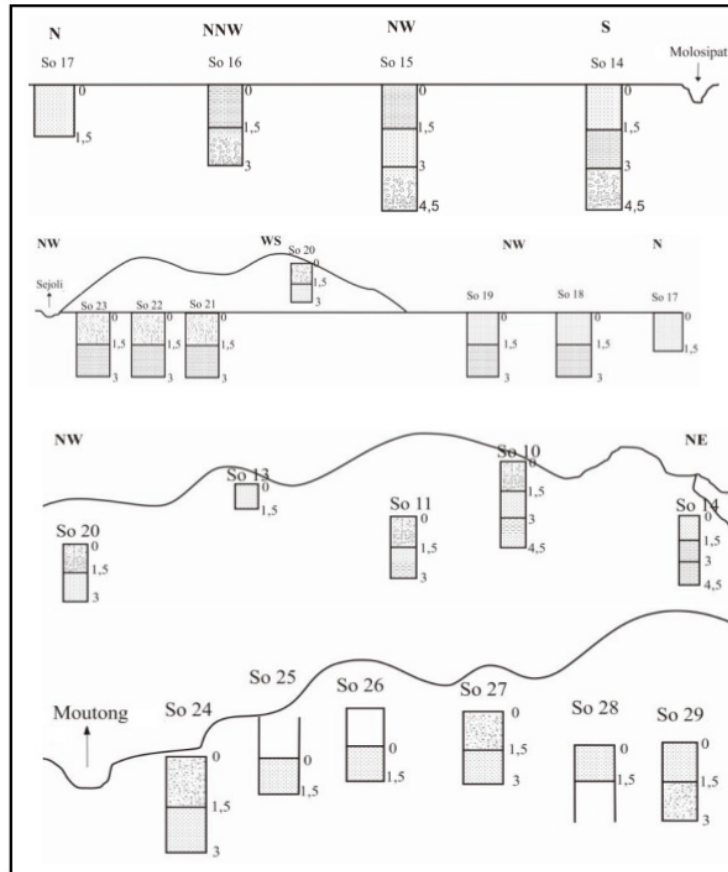


Figure 4. Cross section and fragment differences (no scale)

The sampling point (Figure 5) generally follows the pattern of dendritic river flow. The soil samples were carried out in a soil area of 1 m<sup>2</sup> with relatively shallow depth following rock contact. The roundness analysis used a binocular microscope (100 μm magnification) was carried out at the Laboratory of Optical Minerals, Department of Geology, Hasanuddin University and Analysis of Cu, Ag, Pb, Fe, Zn using AAS (Atomic Absorption Spectrometry) with gravimetric acid digest (GAA03) treatment unless Au was determined by fire assay (FAA40).





Figure 6. (a) Andesite outcrops (b) andesite alteration of sulfide mineralization (c) schist

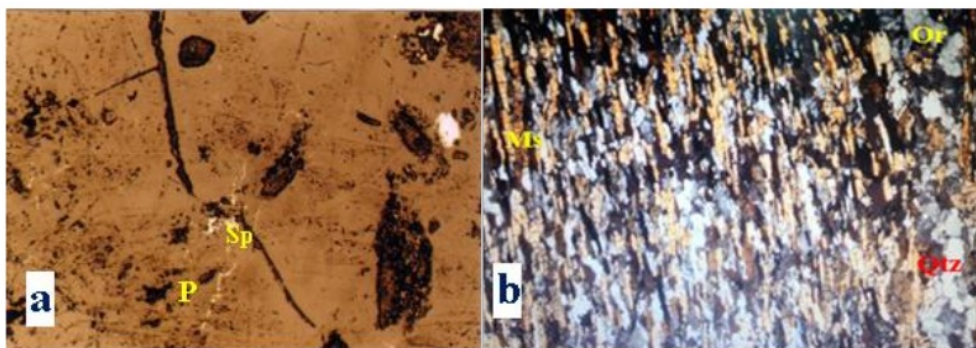


Figure 7. (a) Petrographic quartz (Qtz) muscovite schist, orthoclasts (Or), muscovite (Ms), 50x cross nicol (b) Silicified Andesite, oxidation brecciation, sulfide mineralization; framboid pyrite, sphalerite

### 5. Granular Morphology

Correlation of the transportation environment [10] morphotectonic which distinguishes gold grain characteristics from those affected by various factors, the incidence of gold particles, energy flow, formation of river deposit, time, distance and water chemistry [11].

**MNH**, the northern part of gold granules averages 1.5 to 2 mm, average weight is <0.02-0.04 mg. **MSH**, grain size 0.01 - 0.08mg and average weight <0.02mg. The gold metal is a very soft mineral that naturally undergoes a supergene process in the golden granular transport environment and has potential to be damaged, which contacts rock or mineral fragments that have higher hardness [10]. Generally gold grains are found in the form of nuggets, flake irregular, crystals in sheets from and intergranular overlapping and even of quartz that fill the cavity. Its morphology: irregular 53%; semi spherical 33%; wafer shaped 14%. Some different in determining the morphology of gold grains, there are soil samples, because more gold grains are found in soil than in river flow. Determination of gold grain morphological characteristics uses form classification [12], as an approach to sources by localizing the continuity of sample points with determines the spacing of the sample points horizontally. Based on binocular microscope observations (100 μm magnification) with morphological characteristics, grain surface, mineral associations, and flatness index =  $L + b / 2b$ , where L is length, b is breadth and t is thickness [11] the results of the description of Au grains showed significant morphological differences.

**MNH**. In the distance group (0 to 200 m) the gold granules are relatively homogeneous, the grain side is angular- sub angular (sub angular-angular) following a difference of distance of 200 m or more. Generally it still shows the characteristics of transportation with a rough surface. The Au grade flatness index ranges between 1.0 and 2.7 (Figure 8), trace crystals are still visible in the form of branching inclusions of quartz, sulfide and Fe oxide, as primary environmental characteristics [13].


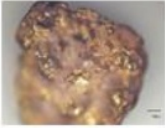

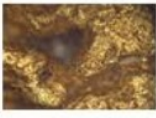
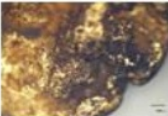


| Distance                 | 0 – 200m  | > 200m  |
|--------------------------|---|---|
| General Shape            |  |  |
| Outline                  | ---   | ---   |
| Surface                  |  |  |
| Primary Crystal Imprints |  | ---   |
| Associated Mineral       |  |  |
| Flatness Index           | 1.0   | 2.7   |

Figure 8. Description of the morphology of MNH gold grains

Granular characteristics, and alteration of andesite mineralization characterize the conditions of a hydrothermal system which depends on the thermodynamics of transportation and rainfall [10]; weathering forms soil residues. Estimated from the steep slope has formed a dispersion around the main andesite outcrop contact with metamorphic schist.

**MSH.** Descriptions at distances (0 to 200m) and (> 200m) are caused only found at a number of sample points. The heterogeneity of grains is rather rounded and extends indicating that the transportation system has many problems. It is indicated that the transportation period other than the fluvial system is also affected by the grain abrasion, the dynamic of transportation indicated by rough backwardness on the grain surface. The Au Grain group is more than 200 m from the mineralized source downstream, rounded, oval, sometimes found in longitudinal forms, trace minerals still strong from source rock are seen which are characterized by structural vug, oxide, quartz. Flatness indexes range between 2.0 and 4.5 (Figure 9).







| Jarak                    | 0 – 200m  | > 200   |
|--------------------------|---|---|
| General Shape            |    |  |
| Outline                  |   |   |
| Surface                  |  |   |
| Primary Crystal Imprints |  |   |
| Associated Mineral       |  |   |
| Flatness Index           | 2.0   | 4.5   |

Figure 9. Description of the morphology of MSH gold grains

Increasing flatness and original shape of gold grains in soil shows the distance of transportation originating from the hydrothermal primary sediment system and quartz vein. However, with varying grade values and some samples that do not show their authenticity, they give an indication of transportation by the tectonic regime and morphological evolution.

## 6. Result and Discussion

**MNH**, description of andesite rock argillic to potassic alteration, dissemination of chalcopyrite, pyrite and slightly bornite. Quite varied Au concentration increased followed by Cu, Pb and Zn (Table 1).

**MSH**, a description of schist, gneiss andesite spot contact shows surface oxidation, minor pyrite quartz veins. Statistics on Pb and Zn concentrations are oxidation weathering transportation products (Table 2).

Table 1. Au and base metal concentrations in the north (in ppm)

|                | <b>Au</b> | <b>Ag</b> | <b>Cu</b> | <b>Pb</b> | <b>Fe</b>  | <b>Zn</b> |
|----------------|-----------|-----------|-----------|-----------|------------|-----------|
| <b>Min</b>     | 0.001     | 0.1       | 0.002     | 0.02      | 27326      | 0.01      |
| <b>Max</b>     | 182.2     | 7.4       | 1118      | 374       | 504000     | 153.4     |
| <b>Mean</b>    | 14.07     | 2.39      | 295.87    | 51.95     | 174328.5   | 39.03     |
| <b>Std.Dev</b> | 50.515    | 2.010     | 345.066   | 98.910    | 144898.131 | 42.243    |

Table 2. Southern Au and base metal concentrations (in ppm)

|                | <b>Au</b> | <b>Ag</b> | <b>Cu</b> | <b>Pb</b> | <b>Fe</b> | <b>Zn</b> |
|----------------|-----------|-----------|-----------|-----------|-----------|-----------|
| <b>Min</b>     | 0.001     | 0.1       | 0.002     | 0.02      | 27326     | 0.01      |
| <b>Max</b>     | 0.001     | 0.4       | 0.02      | 0.31      | 100224    | 1.13      |
| <b>Mean</b>    | 0.001     | 0.233     | 0.008     | 0.180     | 75893.667 | 0.427     |
| <b>Std.Dev</b> | 0.0       | 0.152     | 0.010     | 0.147     | 42060.859 | 0.612     |

The value of R square Au-Cu (0.42) shows a strong correlation compared to Au-Zn (0.18), Au-Pb (0.02) and Au-Ag (0.09). On the probability graphic shows the linearity of the representative sample to the concentration of the normal line Cu, compared to Pb which away from the normal line. Properties of scatter Au indicate that representative elemental accumulation in rock is influenced by the degree of alteration mineralization (Figure 10).

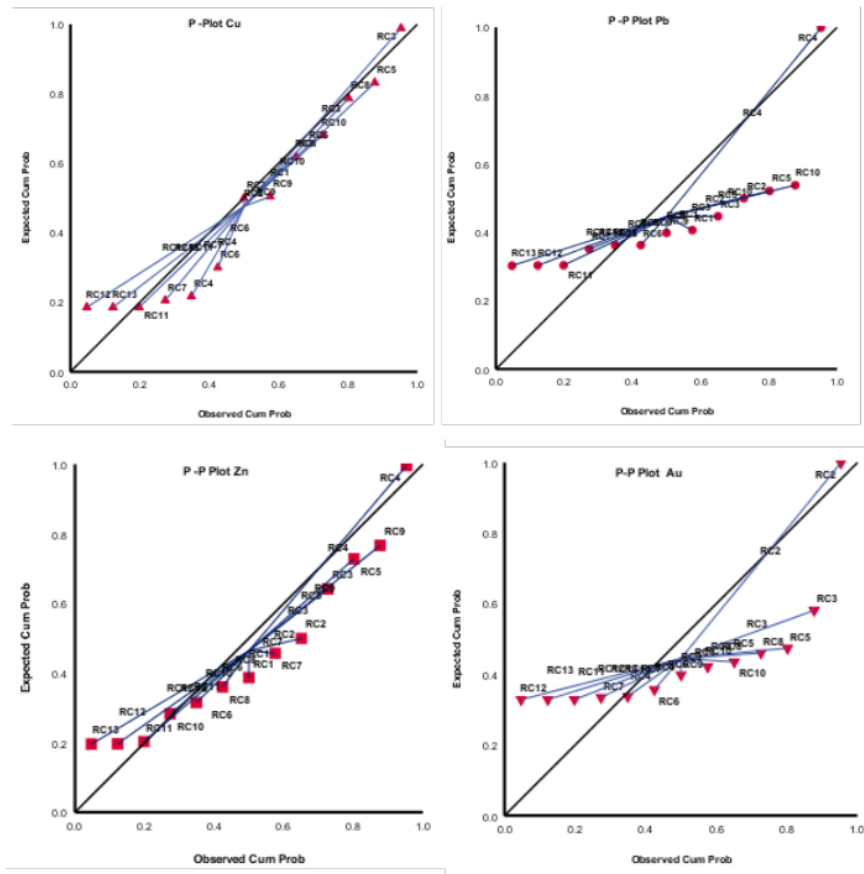


Figure 10. Probability of Au-Cu-Zn-Pb correlation

### 7. Soil Geochemistry

Records control of geological structures are evident in andesite outcrops with systematic fractures (Figure 11a), which are related to the formation of soil residual types (Figure 11b) and soil fluvials (Figure 11c). Soil fluvial distribution is limited by fault zone where the fragment size is dominated by schist boulder, pebble and gravel-sized. Based on the field appearance, the more southward the distribution of fluvial soil thickened (> 0.5 m) mixed with brecciated rock fragments which accumulated in the zone of debris fault.



Figure 11. (a) andesite (b) soil from MNH (c) soil from south MSH

PCA analysis begins by using all matrix components for Au, Ag, Fe, Pb, Zn, Cu. It turns out that there are values of Fe (0.277), Pb (0.385) and KMO (0.452) that have not met the requirements of component analysis, so that Au, Ag, Zn and Cu are continued, the KMO observation correlation coefficient for sampling adequacy is 0.522. Based on the initial eigenvalue value ( $\lambda_1 = 2.033$ ;  $\lambda_2 = 1.416$ ) two factors and variances were formed (50.837% of PC1; 86.229% of PC2) (Table 3), extraction of the variables Ag, Cu, Au, Zn was 86.25%.

Table 3. Total variance variable

**2**  
**Total Variance Explained**

| Comp<br>. | Initial Eigenvalues |          |        | Extraction Sums of Squared Loadings |               |       | Rotation Sums of Squared Loadings |               |       |
|-----------|---------------------|----------|--------|-------------------------------------|---------------|-------|-----------------------------------|---------------|-------|
|           | Total               | % of Var | Cum %  | Total                               | % of Variance | Cum % | Total                             | % of Variance | Cum % |
| 1         | 2.03                | 50.84    | 50.84  | 2.03                                | 50.84         | 50.84 | 1.80                              | 45.08         | 45.08 |
| 2         | 1.42                | 35.40    | 86.23  | 1.42                                | 35.40         | 86.23 | 1.65                              | 41.14         | 86.20 |
| 3         | .36                 | 9.08     | 95.31  |                                     |               |       |                                   |               |       |
| 4         | .18                 | 4.70     | 100.00 |                                     |               |       |                                   |               |       |

*Extraction Method: Principal Component Analysis.*

Through rotation the variable distribution becomes clear and tangible which results in 2 matrix component rotations, according to the number of factors obtained, they are the distribution of 2 variables into factors. The results after rotating are two variables that have a high correlation (cut off point = 0.55) with factor 1, Au (0.953), Ag (0.949); factor 2 is Cu (0.900), Zn (0.902) (Figure 12).

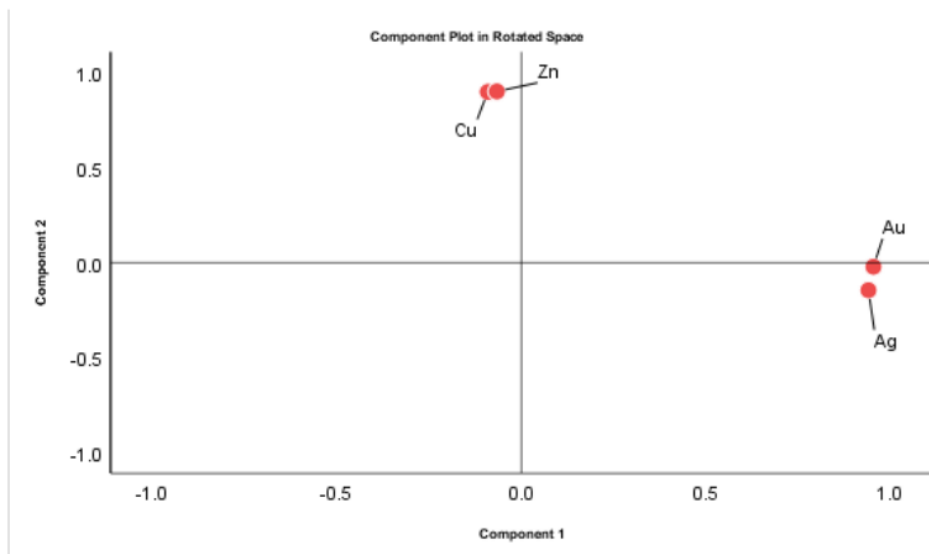


Figure 12. Components of Au-Cu-Pb-Zn rotation plots

The observed gold grains have different morphologies and correlated with weathering levels and transportation mechanisms. Generally strong to moderate weathering occurs in non-mineralized andesite rock through residual stages, whereas in andesite mineralization follows the field of shear structure.

Characteristics of sheets in the gold grain morphology are two types of transportation, namely fluvial transportation and fluvial tectonic transportation. Fluvial transport is associated with the presence of sulfide inclusions, pyrite, sharp edges and veint quartz bonds with other gangue minerals. Fluvial tectonic transportation has the characteristics of gold sheet inclusion in gold grains associated with pyrite, sulfide and oxide (Figure 13), a fairly long range of grade values (2.0 -4.5), correlates with regional tectonic, major fault movement of Palu-Koro and geological structure formation local which affects the distance of transportation; fluvial dynamics [13].

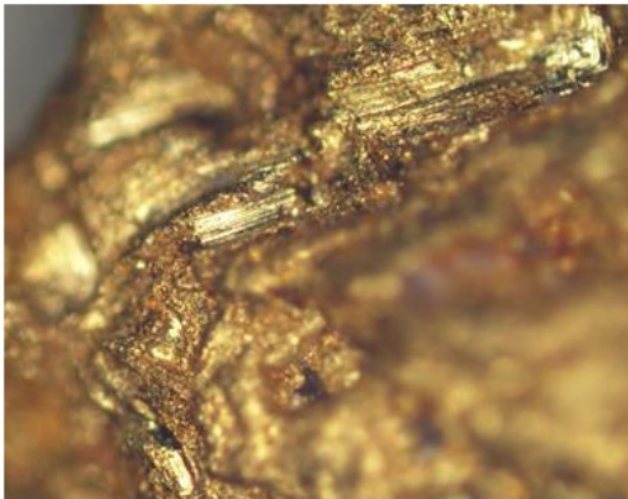


Figure 13. Gold sheet inclusions in grain

Statistics on andesitic alteration rock have strong correlation sequences: Au -Cu> -Zn Au> -Pb> Au - Ag and Cu ~ Pb, while in soil: Au-Ag ~ Cu ~ Zn. This sequence of correlation is a strong indication of the presence of placer deposit sources as hydrothermal deposits: 1) Au-Cu (2) Au-Zn (3) Cu-Pb and (4) Epithermal Au-Ag. This study of placer deposits is one approach to the differences in the dominance of gold grains in soil compared to river deposits and sources of gold aggregates as primary deposits.

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