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Significant of Gold Mineralogical Study for The Chemical Separation of Weathered Ore in Malaysia

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Abstract. This paper provides a mineralogical study on the gold ore sample obtained from a local gold mine in Malaysia that underwent the laterisation process. The mineralogical characteristic of the secondary gold was investigated using the optical microscope study. Then, the presence of other minerals was identified by X-ray fluorescence, X-ray diffraction and scanning electron microscope/energy dispersive X-ray. X-ray mapping was also employed for the determination of the elemental distribution in the gold ore samples. From the optical microscopy and SEM/EDX study, the gold grain was found embedded in the quartz and also was spotted interlocked in iron oxide and arsenopyrite as well within size from sub-microscopic (1<μm) to microscopic (≤10μm) with a flaky type of surface morphology as well as the presence of element of Si, O and Fe. XRD shows the mineral phases of quartz, muscovite and magnetite. In XRM, the gold was also found disseminated on the silicate minerals surface like quartz (SiO₂), chlorite ((Mg₅Al)(AlSi₃)O₁₀(OH)₈) and clay minerals, as also confirmed by the chemical composition presents in the XRF analysis. Hence, from this mineralogical studies, the characteristic of the gold is unsuitable to be processed by physical separation as the submicroscopic gold will tend to be lost during processing and a sustainable processing method such as non-cyanide leaching can be proposed to overcome the problem.

1. Introduction

In the Peninsular Malaysia, there is a large volume of published studies describing the role of the hydrothermal fluid as a conduit which carries the metallic minerals and resulting in the gold mineralization. The precipitation of this hot fluid originated from the metamorphism and magmatic events causing the deposition of the gold in the extensive deformation (brittle-ductile and shearing zone) and develops the gold deposits which mostly mined from quartz lode as well as in the stockwork deposits.

Gold is a native metal that may happen as primary or secondary deposit where the secondary type of gold sometimes comes with very high purity of gold grains instead of an alloy of gold, silver and copper that often formed during the gold occurrences. These secondary gold grains are formed from the weathering process that most likely attacking either through chemically beneath the rock by the help of the supergene solution or mechanically transported that often resulted in depletion of silver content. The lateritic weathering profiles are created as the gold deposit is exposed to the tropical weathering [1] and this prolonged weathering is due to the arid environment where Malaysia is one of the countries having...
tropical rainforest climate with an average annual rainfall of 2500 mm with hold an average temperature of 27°C that is hot and humid all year.

Several studies have revealed that the secondary gold deposit is characterized by several features particularly in morphology and their grain sizes. The gold content also decreases towards the top of the soil profile as it experiences the chemical alteration. This type of gold is mostly displayed by the flat rounded shape resembling the botryoidal type with etch pits as well as corrosion cavities that appeared on the grain surface. Generally, the gold forming in the secondary environment is mostly very fine (<10μm) in size and also found scattered and surface-bound onto the surface of other minerals [2] such as stained quartz vein, iron hydroxides and others.

This paper will focus on the mineralogical characterization of the secondary gold from weathered ore as it is compulsory before the gold deposit is brought to the beneficiation process. Prior to separation and extraction process of the gold, the waste mineral needs to be identified and separated physically and chemically as gangue minerals would affect the quality of final product. With a better understanding on the mineralogy of the gold, this would effectively minimize the cost of gold processing. In this research work, the methods employed to characterize the gold ore are optical microscopy, X-ray diffraction and fluorescence, SEM/EDX analysis and also X-ray mapping.

2. Experimental study

In this research study, the gold ore samples were obtained from a local gold mine in Malaysia. This gold ore sample was collected from the gold-bearing vein that been exposed to the lateritic weathering front. The samples were crushed and ground until passing 80% of 75 μm sieve. The ground ore was blended homogeneously before the analysis while for the ore microscopic study, representative rock samples were prepared as polished mounts and characterized using Scanning Electron Microscope–Energy Dispersive X-ray (SEM/EDX) as well as X-ray Mapping (XRM) analysis. Then, X-ray Fluorescence (XRF) which is a semi-quantitative analysis tool used to determine the chemical composition whereas identification the major mineral phase were done using X-ray Diffraction (XRD) technique.

3. Results and discussion

3.1 Semi-quantitative and Phase Identification Analysis

The elemental contents are analysed by the XRF analysis which is tabulated in Table 1. It shows that silica and alumina were the major compositions present in the gold ore sample with the weight percentage of 75.22% and 16.10% respectively. While other oxide compounds were detected like K₂O and Fe₂O with the weight percentages of 3.23% and 2.80% respectively. This led to the conclusion that silicate minerals such as quartz, feldspar, clay and other were the major gangue minerals as well as iron oxide present in the gold ore sample.

Table 1. XRF analysis of the major elements presents in the bulk ore sample

| Component | Result (%) | Component | Result (%) | Component | Result (%) |
|-----------|------------|-----------|------------|-----------|------------|
| SiO₂      | 75.22      | SO₃       | 0.29       | PbO       | 0.02       |
| Al₂O₃     | 16.10      | MgO       | 0.22       | CaO       | 0.02       |
| K₂O       | 3.23       | TiO₂      | 0.21       | CuO       | 0.01       |
| Fe₂O      | 2.80       | ZnO       | 0.06       | MnO       | 0.01       |
| As₂O₃     | 0.34       | Na₂O      | 0.04       | Au₂O      | Traces     |

In the XRD analysis, the peaks which represent the mineral phases had been plotted and shown in Figure 1. There were three phases that had been identified in the sample where the major phase was quartz mineral, SiO₂ with 81.3% matched with the reference data (98-001-7203). Meanwhile, other
peaks identified were muscovite, $\text{KAl}_2(\text{AlSiO}_2)(\text{OH})_2$ with 18.1% (98-001-1927) and the iron present as $\text{Fe}_3\text{O}_4$ with 0.6% (98-004-0552). The phases reported were referred to the Inorganic Crystal Structure Database (ICSD) as a standard reference. These findings were tally to the XRF result and optical microscopy studies that showing the presence of silicate minerals and iron oxide as gangue minerals.

![figure1]

Figure 1. XRD diffractogram of the gold ore sample (Q: quartz, M: muscovite and I: magnetite)

3.2 Optical Microscopic Study

The images displayed in Figure 2 are the optical micrographs of the thin section obtained from the stained vein and goethite rock sample. The microscopy images were taken in the cross-polarised light. Figure 2A shows elongated biotite was found in the clay groundmass where another silicate mineral; orthoclase feldspar also was spotted. From the modal analysis in Figure 2B, about 90% of quartz is shown and other 10% was iron oxide (FeOx) that show the yellowish-brown colour of iron oxide which outlines the micro-crystalline quartz having grainy medium size with the first order birefringence colour; white to grey. Then, in Figure 2C reveals iron oxides were surrounded by quartz mineral where the quartz at the above region having grey interference colour while at the lower part of quartz was yellowish interference colour indicates the thin section was slightly thick.

![figure2]

Figure 2. Optical microscopy images of thin section samples in cross-polarized light obtained from the (A and B) stained vein and (C) goethite rock (Qz: quartz, FeOx: iron oxide)

In Figure 3, microscopy images of the polished section analysis observed by polarized microscope. The fine size gold grain was observed to be embedded in the quartz and also was spotted interlocked in brownish iron oxide and arsenopyrite. The presence of iron oxide minerals pseudomorphs after sulphide
minerals is an indication that the ore had been exposed to weathering. Description of minerals in the photomicrograph of thin section study was compared to the reference images obtained from Mackenzie et.al. (1980), Raith et al. (2012) and Goeke (2015). For the optical microscopic study of the polished section, the images were referred to the Reflected Light Microscopy by Francis, (2013), Atlas of Ore Minerals by Picot and John, (1982) as well as literature by Berrezueta et al. (2016).

![Figure 3. Optical microscopy images of polished section samples observed by polarizing microscope in (A) quartz vein (B) goethite (Qz: quartz, Asp: arsenopyrite, FeOx: iron oxide and Au: gold)](image)

### 3.3 Scanning Electron Micrograph Study

Figure 4A portrayed a very fine gold that was found embedded in the quartz at the spot A while Au also was detected together with Mg, Al, Si and O (chlorite) in the spot B. Then, in Figure 4B reveals the presence of the particle of Au and O with a flaky morphology around 0.5 μm found in the region containing the abundant presence of Si and O (quartz mineral). Further, in Figure 4C, a gold grain with an estimated size of 20 μm was found associated together with the elements of Fe and O at spot C while there also a gold that still interlocked in arsenopyrite in spot D. From here, it can be said that this iron oxide (spot C) was resulting from the oxidation of sulphide mineral (spot D) that has been undergone weathering environment. These findings are similar in the book written by Brinck, 1956, who reported that the secondary gold grain present in the iron oxide (as inclusion or embedded) has a flaky morphology and fine in size.
Figure 4. SEM Back-scattered electron micrograph and EDX diffractogram of gold grains in (A) quartz mineral and (B and C) goethite

3.4 X-ray Mapping Study

X-ray mapping is a tool to study the elemental distribution in the interest area of the sample. The distribution of the elements; O, Mg, Al, Si and Au are presented in Figure 5A – 5E while in the Figure 5F shows the overlay minerals association and distribution in the gold ore sample. From the photomicrograph shown in Figure 5E, the gold grains were scattered and surface-bound onto the silicate minerals like quartz, chlorite and clay minerals as the Si and O were majorly found in the sample. Hence, the gold ore samples that being studied was concluded as gold colloids and occur as submicroscopic grains from this mineralogical studies.
Figure 5. X-ray mapping photomicrographs of elemental distribution of O, Mg, Al, Si, and Au presence in the quartz vein of the gold ore sample

4. Conclusion

From the X-ray analysis, three mineral phases had been identified which are quartz, muscovite as well as iron present as magnetite. The associated oxides present were SiO$_2$, Al$_2$O$_3$, K$_2$O, Fe$_2$O$_3$ and As$_2$O$_3$. From optical microscopy and SEM/EDX study, the gold grain was found interlocking in quartz, iron oxide and arsenopyrite as well as spotted as oxide of about 5μm in size with a flaky surface morphology. In XRM, the gold was also found disseminated on the silicate minerals surface like quartz (SiO$_2$), chlorite ((Mg$_5$Al)(AlSi$_3$)O$_{10}$(OH)$_8$) and clay minerals, as also confirmed by the chemical composition presents in the XRF and in SEM/EDX analysis displayed in Figure 4A at spot B where Au was detected together with chlorite mineral. The presence of sulphide minerals associated with iron oxide proof that the deposit has undergone the lateritisation process resulting in the formation of iron oxide minerals (pseudomorphs after sulphides). This lead to the staining of the nearest quartz from the oxidation of iron. Hence, this mineralogical studies led to the conclusion that the very fine gold found in the sample being studied is the result of lateritic weathering attacking the outcropped of the gold ore deposit. Thus, this type of gold ore is unsuited to be recovered by physical separation as the submicroscopic to microscopic size of gold grain will tend to be lost during the process.

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