Acid Mine Drainage from Epithermal Gold Deposits: Characterization and Classifying for Various Rock Types

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Abstract

Epithermal gold deposits, both low-sulfidation and high-sulfidation, are the main gold deposits in Indonesia. For mining and metallurgical purposes, rocks from epithermal gold deposits are classified based on alteration, and lithology or rock types/lithotypes. This study aims to ascertain the possibility of acid mine drainage classification using rock types applied in mining companies. Classification of acid mine drainage attributed to the existing individual rock types will be beneficial for acid mine drainage and waste management. Characterization of waste rock in epithermal deposits which are based on rock types (alteration, metallurgical extractability and lithology) is associated with the geochemical classification of acid mine drainage. Alunite as a product of alteration processes gives a false indication of acid mine drainage classification, thus alunite-rich waste rock needs to be classified separately.

Keywords: Epithermal Deposits, Alteration, Classification, Acid Mine Drainage, Alunite

Introduction

Epithermal gold deposits, both low-sulfidation and high-sulfidation, are the main gold deposits in Indonesia. In Indonesia, epithermal deposits are related to major Cenozoic magmatic arcs, which are related to tectonic activities of plate movements. There are five major magmatic arcs related to this type of deposit, i.e., Sunda-Banda Arc, Kalimantan Arc, Sulawesi Arc, Halmahera Arc and Papua Arc, as shown in the following figure.

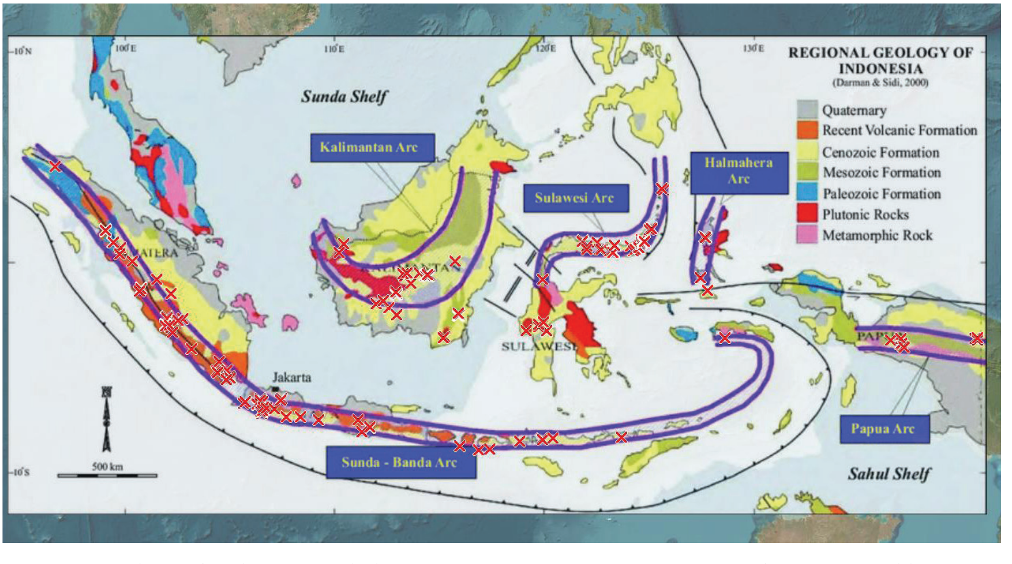

Figure 1 Geology of Indonesia, including Major Cenozoic Magmatic Arc and Primary Gold Deposits (denotes by red × marks). Modified from Darman & Sidi, 2000

Epithermal gold deposits are formed as a result of interaction between hydrothermal liquids with surrounding rocks producing different minerals called mineral alteration and assemblages. Various minerals can be deposited in the epithermal system, mainly regulated by the pH of the hydrothermal solution and temperature, as explained in the following figure.

Alteration or mineralogical and textural changes in host rock are the results of reactions between host rock and hydrothermal solutions deposited by various minerals such as phyllosilicates including clay minerals, alunite and the most important mineral in acid mine drainage formation i.e., pyrite. Jarosite and alunite as sulfate minerals are at a lower temperature in a high-sulphidation epithermal system. These minerals are also observed as secondary precipitates or minerals from acid mine drainage generation in a broader temperature condition. On the other hand, pyrite occurs at all temperatures and in acidic to neutral epithermal deposition (epithermal high sulphidation – epithermal low sulphidation). Calcite as a neutralizing mineral is also found in alkaline depositional environments at all temperatures. Mineral deposition processes are associated with mine drainage formation and their geochemical characterization. Management of acid mine drainage is complex and problematic not only because the occurrences of pyrite vary in different rock types, but also other minerals related to acid mine drainage are deposited differently.

For mining and metallurgical purposes, rocks from epithermal gold deposits are classified based on alteration, and lithology. Oxidation states related to metallurgical extractability, the higher oxidation types (completely oxidized), the easier the leaching process of the material, since most sulphides are already 'oxidized'. Alteration related to the changes of aluminosilicates into other forms of aluminosilicates, i.e., micas and clay minerals. Lithology is related to major mineral constituents and the texture of these minerals.

This study aims to ascertain the possibility of acid mine drainage classification using rock types applied in mining companies. Classification of acid mine drainage attributed to the existing individual rock types will be beneficial for remediation of acid mine drainage and for waste management. Samples of waste rocks from different epithermal deposits and various rock types in

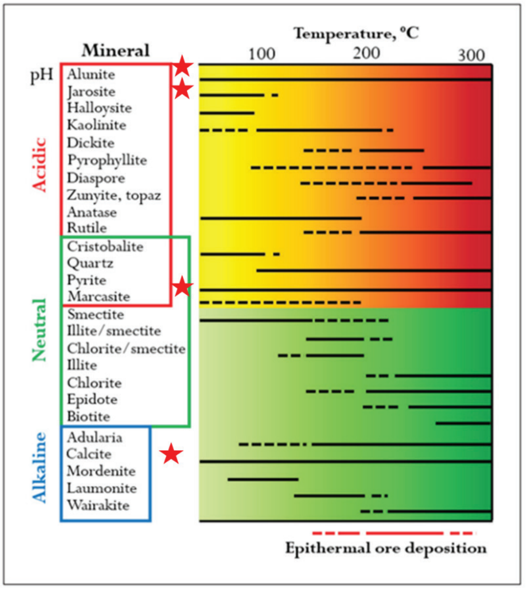

Figure 2 *Mineral Stability at various conditions of temperature and pH at epithermal deposition. Minerals related to acid mine drainage are marked by red stars. (Hedenquist et.al., 1996)*

Table 1 Sample Description

Sample ID	Lithology	Alteration	Oxidation	Notes
Sample 1	Brecciated Diatreme	SM (Silica Massive)	Moderately Oxidized	High Alunite
Sample 2	Brecciated Diatreme	AA (Advance Argillic)	Moderately Oxidized	High Alunite
Sample 3	Vulcanic-Dacitic	SM (Silica Massive)	Completely Oxidized	High Alunite
Sample 4	Vulcanic-Dacitic	AR (Argillic)	Completely Oxidized	-
Sample 5	Vulcanic-Dacitic	AR(Argillic)	Fresh/Unoxidized	-
Sample 6	Vulcanic-Dacitic	AA (Advance Argillic)	Completely Oxidized	-
Sample 7	Diatreme	AA (Advance Argillic)	Fresh/Unoxidized	-

Indonesia are characterized using static tests, mineralogical and elemental tests and kinetic tests using the free draining column leach test (FDCLT) method in the laboratory

Methods

Samples

Selected samples are taken from different epithermal gold deposits of various magmatic arcs, mostly from mines located in the Sunda-Banda Arc and Sulawesi Arc, which are tested in the Mining Environmental Laboratory, Institut Teknologi Bandung in the period of the year 2014 – 2021.

Rock types as previously described are lithology (2 classes: diatreme/brecciated diatreme and volcanic-dacitic rocks), alteration (3 classes: silica massive, advanced argillic and argillic) and oxidation states (fresh, moderately oxidized, completely oxidized). Samples 1 – 3 are identified as high-alunite samples since alunite is detected for a fraction of more than 2% in those samples based on UV-VIS-NIR Spectroscopy, XRD and XRF test results. Alunite is usually found in samples from silicic (silica massive mostly) and advanced argillic alteration.

Testing Methods

Static tests based on AMIRA 2002 (adopted in SNI Indonesian National Standards No. 7742:2021) and kinetic tests using the free draining column leach test (FDCLT) method were performed for all samples. Kinetic test runs for 100 days with different wet-dry cycles (initiated by daily spraying then 3 days spraying and weekly spraying). Water used for the kinetic test was deionized water (pH ~7.00 and TDS < 1mg/L).

Result and discussion

Static Test results

The static test results for all 7 samples are shown in the table below:

Table 2 Static Test Results

Sample ID	pH paste	NAG pH	NAG pH= 4.50	NAG pH= 7.-00	TS	MPA	ANC	NAPP	NPR	Geochemical Class.
	NAG Test				Acid-Base Accounting					
			kg H_2SO_4/ton		%		kg H_2SO_4/ton			
Sample 1	6.76	4.89	<0.5	2.7	4.95	151.59	<0.5	151.59	0	UC
Sample 2	7.13	4.50	<0.5	3.6	3.9	119.44	<0.5	119.44	0	UC
Sample 3	6.5	4.77	<0.5	10.5	3.75	114.84	<0.5	114.84	0	UC
Sample 4	5.04	5.19	<0.5	12.7	0.11	3.37	<0.5	3.37	0	UC
Sample 5	4.78	2.88	10.3	15.4	4.05	124.03	<0.5	124.03	0	**PAF**
Sample 6	5.77	5.30	<0.5	13.7	0.28	8.58	<0.5	8.58	0	UC
Sample 7	4.04	2.23	79.9	91	4.32	132.3	<0.5	132.3	0	**PAF**

Note: NAG=net acid generating, TS=total sulphur; MPA=Maximum Potency Acidity; ANC=Acid Neutralizing Capacity; NAPP=Net Acid Producing Potency, NPR=Neutralizing Potency Potential; UC=uncertain; PAF=potentially acid-forming.

From static test results, all samples from the alunite group are characterized as uncertain and the MPA value exceeds 110 kg H_2SO_4/ton. Sample 4 and Sample 6 are characterized as uncertain, yet MPA values are less than 5 kg H_2SO_4/ton and NAG pH value > 5.00. Sample 5 and Sample 7 are categorized as potentially acid-forming with NAG value < 3.00 and MPA > 120 kg H_2SO_4/ton

Kinetic Test Results

Kinetic test results, i.e., leachates pH values for test running of 100 days are shown in the following figures (figure 3 for Samples 1 – Samples 4 and Figure 4 for Samples 5 – Samples 6).

Samples 1, 2 and 3 which are grouped as alunite group samples produced slightly acid leachates during the kinetic test runs (pH leachates > 4.00). On the other hand, sample 4 and sample 6 which are characterized as uncertain (UC) are producing circumneutral pH (>6). Sample 5 and sample 7 are producing acidic leachates (pH <4.00) and are also characterized as PAF materials by static test results.

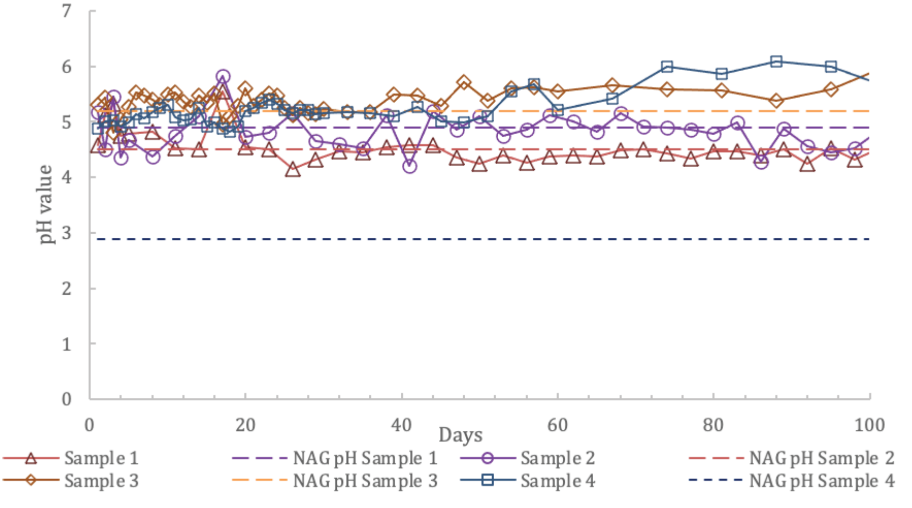

***Figure 3** Kinetic Test Results (pH Value) for Sample 1 – Sample 4*

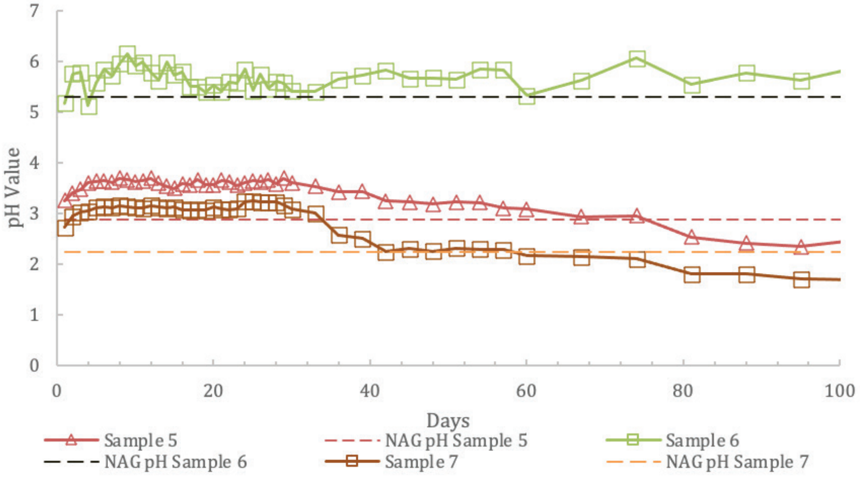

***Figure 4** Kinetic Test Results (pH Value) for Sample 5 – Sample 7*

Geochemical Classification based rock types

Based on static test and kinetic test results and further categorization based on various lithotypes, geochemical classification is related to oxidation states, which is understandable since the higher the oxidation states (fully oxidized), the more oxidized mineral is found. These samples are categorized as non-acid forming. On the other hand, fresh or moderately oxidized samples are categorized as potentially acid-forming since sulphide minerals are more abundant, including pyrite as acid producing mineral. Other lithotypes such as alteration and lithological rock types are less related to the geochemical classification of acid mine drainage since the alteration is only indicating the evolution of aluminosilicates minerals in the samples. Various lithological rock types are also related to major minerals in the rock samples (quartz and alumino-silicates) and are related least to the geochemical classification of acid mine drainage

Alunite Group Geochemical Classification

Alunite group geochemical classification is separated from previous geochemical characterization. Alunite reaction with acidity yields sulphate, potassium, aluminium and water, as described as follows:

$$K\,Al_3\,(SO_4)_2(OH)_6 + 3H_2O \leftrightarrow 3Al(\mathrm{OH})_3 + \mathrm{K}^+ + 2\mathrm{SO}_4^{-2} + 3\mathrm{H}^+$$

Alunite production of acidity is lesser in extent than oxidation of sulphide or dissolution of soluble iron sulfate minerals since alunite is less soluble (Lapakko, 2002; Nordstrom, 1982). High-alunite samples are overestimated in producing acidity, as showed by very high MPA values, yet producing NAG pH value of more than 4.00) since MPA is calculated from total sulphur and assumed all sulphur is in form of sulphide minerals (i.e. pyrite). Nevertheless, alunite group samples are classified by their NAG pH and kinetic test pH value. And the final classification is barren or non-acid forming.

Conclusions

Characterization of waste rock in epithermal deposits based on rock types (alteration, metallurgical extractability and lithology) is compatible with the geochemical classification of acid mine drainage. The classification of rock based on oxidation type and metallurgical extractability is closely related to the geochemical classification of acid mine drainage. Alunite as a product of alteration processes gives a false indication of acid mine drainage classification, thus alunite-rich waste rock needs to be classified separately due to high sulphur content but produces less-acid leachates in laboratory kinetic tests.

Acknowledgements

The authors would like to thank all supported parties for their kind assistance and help during data acquisition, data processing, laboratory testing and manuscript preparation.

References

AMIRA (2002) ARD Test Handbook. Project P387A. Prediction and Kinetic Control of Acid Mine Drainage, AMIRA International Limited, Melbourne, Australia.

Darman H. Sidi F. H. & Ikatan Ahli Geologi Indonesia. (2000). An outline of the geology of Indonesia. Indonesian Association of Geologists.

Hedenquist, J & Arribas, A & Gonzalez-Urien, E. (2000). Exploration for Epithermal Gold Deposits. Reviews in Economic Geology. 13. 245-277.

Lapakko, K. (2002) Metal Mine Rock and Waste Characterization Tools: An Overview. Mining, Minerals and Sustainable Development, No. 67.

Nordstrom, D. K. (1982). The effect of sulfate on aluminum concentrations in natural waters: some stability relations in the system Al2O3-SO3-H2O at 298 K. Geochimica et Cosmochimica Acta, 46(4), 681–692. doi:10.1016/0016-7037(82)90168-5