Prediction Potential Acid Mine Drainage of Epithermal High Sulfidation Deposits using Static Test

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Abstract. Acid mine drainage can be predicted by testing the geochemical characteristics of rocks, to be knowing acid-forming rocks and acid neutralizing. Prevention and mitigation efforts from acid mine drainage can be predicted by knowing the characteristics of rocks and looking for the direct contact of acid rocks with air and water. The static test aims to determine the potential for acid formation that occurs in rocks as a first step to characterize rocks. Tests were carried out on argillic silica alteration rock samples from the Lanut site, PT J-Resources Bolaang Mongondow. The calculation of total sulfur shows a smaller percentage of the value of the advance argillic than the silisic sample. The results of advance argillic samples, NAG pH> 4.5 were obtained and the value of Net Acid Producing Potential (NAPP) in the range of 110-153 kg H2SO4 / ton rocks which means that the potential nature of rocks cannot be ascertained PAF or NAF. Whereas for silisic alteration rock samples the pH value of NAG <4.5 and NAPP values in the range of 146 - 355 kg H2SO4/ ton rocks means silisic alteration has the potential acid forming.

1. Introduction
The series of mining activities have never been separated from the environmental problems posed especially in mining and processing activities. One of the impacts of mining activities is the exposure of parts of rocks that allow contact with air or rainwater which has the potential to create acid mine drainage. Acid mine drainage or acid rock drainage is water in mining or excavation activities that are acidic or have high acidity and formed as a result of oxidation of sulfide minerals accompanied by the presence of water [1-3]. The formation of acidic water produced in mining activities affects water quality which is not only acidic but also dissolved metal content in the water to increase due to a decrease in pH (low pH).

Gold ore deposits (Au) in epithermal high sulfidation are exploration targets that produce acidic water characterized by host rock consisting of acidic volcanic rocks intermediate with depth formation between 500-2000 meters and temperatures of 100°C-320°C. Epithermal high sulfidation deposits are formed by a system of hydrothermal fluid originating from a sufficiently deep magmatic intrusion, this fluid moves vertically and horizontally through fractures in a relatively high chain (200°C-300°C), this fluid used by a magmatic fluid with a content high acid consisting of HCl, SO₂, H₂S [4-6].

Gold mineralization is influenced by hydrothermal solutions that flow through rock permeability, resulting in alteration processes. Altered rocks can be defined as changes in mineral composition in rocks. The initial minerals can turn into one or more new minerals due to changes in conditions, such as
changes in temperature, pressure, or chemical conditions. The type of mineralization and alteration in an area has its characteristics which are often characterized by the existence of a certain set of minerals.

The alteration zone formed in epithermal high sulfidation deposits includes the following the silicic zone, advance argillic zone, argillic zone, and propylitic zone. The formation process of gold deposits generally found in the silicic alteration zone which dominated by hydrothermal solutions and in the deepest zone. In advanced argillic, argillic, and propylitic alteration zones dominated by meteoric water and clay minerals formed that rocks in this alteration zone included in the waste material. The excavation process on waste material allows the formation of acid mine drainage due to the exposure of sulfide minerals cause direct contact with water and air in mining activities so that prevention and mitigation efforts needed before the formation of acid mine drainage could be environmental pollution impact.

Management of acid mine drainage can be predicted by carrying out various geochemical characteristics tests and rock mineralogical tests so that the rocks known to be acidic (Potentially Acid Forming (PAF)) or not (Non-Acid Forming (NAF)). Prevention and mitigation efforts from acid mine drainage can be predicted by knowing the characteristics of rocks and seeking acidic rocks that do not experience direct contact with air and water.

2. Formation of acid mine drainage

Acid mine drainage formed because of the availability of three main elements, which are sulfide minerals, oxygen, and water. Sulfide minerals are a source of sulfur that is oxidized and forms acids, oxygen oxidizing elements of sulfur and water is a washing medium produced by sulfur oxidation. Acid mine drainage formed through a series of complex geochemical and microbial reactions that occur when interaction water and pyrite minerals (Iron Sulfide/FeS$_2$) [3].

The process of forming acid mine drainage formed by three components including sources, transport media and receptors. The three components can vary in type depending on commodities, climate, mining stages, and others. Sources are things that can the formation of acid mine drainages such as mining activities and processing facilities related to sulfides. Transportation media related to climate and season which can influence the formation process of acid mine drainage sources and transportation mechanisms from the results of the formation of acid mine drainage. While the receptor is an environment that receives the results of formation acid mine drainage, for example, groundwater, surface water or wetland. The chemical reactions commonly used to explain the oxidation process of mine acid water [4]:

$$\text{FeS}_2(s) + 15 \text{O}_2(g) + 14 \text{H}_2\text{O}(l) \rightarrow 4 \text{Fe(OH)}_3(s) + 8 \text{H}_2\text{SO}_4(aq)$$

3. Static test

The static test is the first step for rock characterization designed to calculate the balance between acid-forming components (sulfide minerals) and acid-consuming components (carbonate minerals) in rock samples [3]. Static tests do not consider the rate of acid formation and neutralization. The purpose of this test is to determine the potential for acid formation that occurs in rocks.

There are two types of tests to determine the potential for acid formation, through the formation of independent components that can generate acid and neutralize an acid; and calculations in one value used to describe the possibility of acid being generated or the release of acid contained in the sample. The description of the test includes [1], [3], [9]:

3.1. Paste pH

Paste pH obtained from the pH measurement of the paste formed from a mixture of de-ionized water and rock samples with a weight ratio of 1:2 after being left for about 10 minutes. Paste pH test shows the interaction of acidity and alkalinity of the material at the beginning of the material exposed and reacts with water.
3.2. Net Acid Generating (NAG)
Testing is done by measuring the acidity of the rock solution and the number of cations needed by the solution to achieve a certain degree of acidity (the reaction of acid formation and neutralization takes place simultaneously) which is by environmental quality standards. This NAG test will provide an overview of the reactivity of sulfide content. In the testing process, hydrogen peroxide will be added to the sample to rapidly oxidize the reactive sulfide. This method aims to evaluate the balance between acid formation processes (sulfide mineral oxidation) and acid neutralization processes (dissolution of alkaline carbonates, displacement of changeable bases, and silicate weathering). The value obtained from this method is the value of Maximum Potential Acidity (MPA), Net Acid Producing Potential (NAPP), Acid Neutralizing Capacity (ANC).

3.3. Total sulfur
This test was conducted to determine the total sulfur content in rock samples. The measurement of total sulfur is carried out with high-temperature combustion with a heating furnace. The sulfur content in the sample consisted of 3 components: the most reactive S sulfide (pyritic), S organic, and S sulfate.

4. Sample description
Samples were tested for epithermal high sulfidation deposits of ore rock in gold mine (Au) type from Lanut site, PT J-Resources Bolaang Mongondow, North Sulawesi. This sample distinguished based on alteration. Sample total is six samples consisting of advance argillic alteration rock samples and silicic alteration rock samples.

Table 1. Description of rock samples.

| Sample code | Alteration     | Depth from (m) | Depth to (m) | Thick (cm) | Rock type       | Zone    |
|-------------|----------------|----------------|--------------|------------|-----------------|---------|
| AA1         | Advance-Agillic| 11.7           | 15.2         | 285        | Ore - Transition| Oxide   |
| AA2         | Advance-Agillic| 10.4           | 12           | 165        | Ore - Oxide     | Transition |
| AA3         | Advance-Agillic| 22.5           | 27           | 170        | Ore - Oxide     | Oxide   |
| SI1         | Silisic        | 40.55          | 43.4         | 350        | Ore - Sulphide  | Sulphide |
| SI2         | Silisic        | 33.35          | 35           | 160        | Ore - Transition| Transition |
| SI3         | Silisic        | 36.3           | 38           | 445        | Ore - Transition| Oxide   |

5. Result
Classifications carried out based on static tests grouped into three, i.e. Potentially Acid Forming (PAF), Uncertain (UC) and Non-Acid Forming (NAF). The test results of the rock classification parameters were obtained for determining the results of the measurement criteria tested. The PAF criteria if the NAPP value was ≥ 0; NAG pH ≤ 4.5; NAF criteria based on NAPP value ≤ 0; NAG pH ≥ 4.5, for UC (Uncertain) criteria, NAPP is positive and has a NAG pH > 4.5 or when NAPP is negative and has NAG pH <4.5.

Determining the geochemical classification of ore rock samples using static test data. NAPP (MPA-ANC) and NAG pH test were obtained (Table 2), then NAPP and NAG pH were graphed so that the geochemical characteristics of the rock were known. Sample categorized as PAF if NAG pH < 4.5 and has a positive NAPP value. Whereas for NAF if it has NAG pH> 4.5 and negative NAPP value. If NAG pH and NAPP are outside of the two criteria, the rock sample will be categorized as UC (uncertain),
which is still uncertain whether the rock is PAF or NAF. Based on the criteria determined the geochemical classification of ore rocks.

Based on the screening criteria for the initial classification of rock geochemistry, silicic alteration samples have the potential to form acids which have NAG pH < 4.5 and indicate Potentially Acid Forming (PAF). While advance argillic alteration samples classified as Uncertain (UC), seen from the ANC and MPA comparison values (Table 2) the sample has an acid-neutralizing capacity = 0, it means that advance argillic alteration rocks tend to have Potential Acid Forming (PAF). Whereas for NAG pH, advance argillic alteration samples classified as NAF or have no potential to form acids. The sample tends to have a high NAPP value because of the high percentage of total sulfur. However, not all reactive sulfur so that epithermal high sulfidation samples are not suitable for NAPP testing and if seen from NAG pH, advance argillic alteration sample classified as NAF because it has NAPP > 4.5.

**Table 2. Static test result.**

| Sample code | Paste pH (1:2) | Net Acid Generation (NAG) | Total sulfur (%) | MPA (kg H₂SO₄/ton rock) | ANC (kg H₂SO₄/ton rock) | NAPP (kg H₂SO₄/ton rock) |
|-------------|----------------|---------------------------|-----------------|------------------------|------------------------|-------------------------|
| AA1         | 6.06           | 4.71                      | 0               | 5                      | 4.41                   | 135.0                   |
| AA2         | 6.09           | 5.24                      | 0               | 4.4                    | 3.59                   | 110.0                   |
| AA3         | 6.40           | 4.63                      | 0               | 4                      | 4.99                   | 153.0                   |
| SI1         | 4.87           | 2.32                      | 79.5            | 91.1                   | 11.6                   | 355.0                   |
| SI2         | 5.52           | 2.47                      | 52.3            | 62.5                   | 8.09                   | 248.0                   |
| SI3         | 6.20           | 2.53                      | 39.3            | 47                     | 4.78                   | 146.0                   |

**Figure 1.** Screening criteria for geochemical classification of rock samples

**6. Conclusions**

The sample testing consisted of six samples, each representing advanced argillic alteration rock samples and silicic alteration rock samples in epithermal high sulfidation deposits. Sample characterization using
a static test method which is a test of the initial characteristics of acid-forming rocks. The tests carried out it was obtained for advance argillic samples classified in the NAF category based on the NAG pH > 4.5 and NAPP were high but had unreactive sulfur. Characteristics of silicic alteration are strong PAF which can be seen from the average value of NAG pH < 4.5, i.e. SI1 pH 2.32; SI2 pH 2.47 and SI3 pH 2.53 and based on NAPP values and total sulfur have a greater value than advance argillic alteration samples.

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