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# Acid Mine Drainage and Its Characteristics at Kyaukpahto Gold Mine, Myanmar


Dr. Thant Swe Win, Assistant Director

Department of Mines


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Thant SweWin[1, 2], Hideki Shimada[2], Akihiro Hamanaka[2], Takashi Sasaoka[2], Shinji Matsumoto[3], Myo Min Tun[4]

[1]Department of Mines, Ministry of Natural Resources and Environmental Conservation, Nay Pyi Taw, Myanmar
[2]Department of Earth Resources Engineering, Faculty of Engineering, Kyushu University, Fukuoka 819-0395, Japan
[3]Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, 305-8567, Japan
[4]Department of Geology, Kyaukse University, Mandalay, Myanmar

Corresponding Author's Email: mrthantswewin@gmail.com

## Abstract

Kyaukpahto gold mine located in the Kawlin Township, Sagaing Region of Myanmar is the first open pit and the largest gold mine of Myanmar. Gold ore are exploited by open-pit mining and waste rocks are disposed as waste dumps near mine site. Large amount of waste rocks containing metal sulfides such as pyrite, arsenopyrite, and chalcopyrite are exposed to the surface, favoring the metal sulfides in reaction with air and water, and produce acidic water. High values of hardness and heavy metal concentrations are observed in mine water and apparently reduce the quality of water and create potential threat to nearby environment. There is a possibility of AMD generation in the open pit and at the low grade ore dump. This work focuses on assessment of the potential acid-forming waste rocks and characterization of these waste rocks in Kyaukpahto gold mine. Waste rocks and water samples were taken from the open pit, low grade ore dump, and waste dumps and subjected to various tests and analyses such as NAG test, ANC test, Paste pH test, Paste EC test, XRF, XRD, ICP-MS analyses. Based on the results of the chemical tests and analyses, waste rock samples collected from open-pit and low-grade ore dump are identified as PAF rocks which particularly concerned with the potential generation of acidic mine water. Two-step batch leaching test indicated that low pH value (pH 4) and elution of metal ions such as As, Al, Fe, Cu, and $SO_4^{2-}$ were observed with the high concentration from the samples. Elution of As is higher than other metal ions and this elution process will take place over a longer period than other metal ions. Thus, it is very critical to take appropriate measures against generation of AMD, such as controls on sulfides oxidation, and reduction of metals elution.

**Keywords:** Acid Mine Drainage**,** Gold Mine, Kyaukpahto, Metal Sulfide, Waste Rock

# မြန်မာနိုင်ငံ၊ ကျောက်ပုထိုးရွှေသတ္တုတွင်းရှိ မိုင်းအက်စစ်ယိုစိမ့်မှုနှင့် ၎င်း၏ ဝိသေသလက္ခဏာများ

ဒေါက်တာသန့်ဆွေဝင်း၊ လက်ထောက်ညွှန်ကြားရေးမှူး

သတ္တုတွင်းဦးစီးဌာန

## စာတမ်းအကျဉ်း

စစ်ကိုင်းတိုင်းဒေသကြီး၊ ကောလင်းမြို့နယ်တွင်တည်ရှိသော ကျောက်ပုထိုးရွှေသတ္တုတွင်းသည်မြန်မာနိုင်ငံတွင် ပထမဆုံးနှင့် အကြီးဆုံး Open-pit ရွှေသတ္တုတွင်းဖြစ်ပါသည်။ အဆိုပါ ရွှေသတ္တုတွင်းအား Open-pit mining နည်းစဉ်ဖြင့် ထုတ်လုပ်ပြီး စွန့်ပစ်ကျောက်များအား သတ္တုတွင်းလုပ်ကွက်အနီးရှိ စွန့်ပစ်မြေစာပုံတွင်စုပုံပါသည်။ Pyrite၊ Arsenopyrite နှင့် Chalcopyrite ကဲ့သို့သော သတ္တုဆာလ်ဖိုက်များပါဝင်သည့် စွန့်ပစ်ကျောက်အများအပြားသည် လေနှင့်ရေတို့နှင့်ထိတွေ့ဓာတ်ပြုပြီး အက်စစ်ဓာတ်ရှိသော ရေအဖြစ်ပြောင်းလဲသွားပါသည်။ Mine Water တွင် ရေစေးများနှင့် Heavy metal ပါဝင်မှုများကို တွေ့ရှိရပြီး ရေ၏အရည်အသွေးကို လျော့ကျစေကာ အနီးနားရှိသဘာဝပတ်ဝန်းကျင်ကို အန္တရာယ်ဖြစ်စေသောခြိမ်းခြောက်မှုများဖြစ်နိုင်ပါသည်။ Open-pit နှင့် Low-grade ore dump နေရာတွင် Acid Mine Drainage Generation ဖြစ်နိုင်ချေရှိကြောင်းတွေ့ရှိရပါသည်။ ဤသုတေသနသည် ကျောက်ပုထိုးရွှေသတ္တုတွင်းရှိ အက်စစ်ဓာတ်ထွက်နိုင်သော စွန့်ပစ်ကျောက်များနှင့် ၎င်းတို့၏ ဝိသေသလက္ခဏာရပ်များအပေါ်အကဲဖြတ်ခြင်းအား အဓိကထားလုပ်ဆောင်ခြင်းဖြစ်သည်။ စွန့်ပစ် ကျောက်များနှင့် စွန့်ပစ်ရေနမူနာများကို Open-pit, Low-grade ore dump နှင့်

waste dump တို့မှ ရယူပြီး NAG test, ANC test, Paste pH test, Paste EC test, XRF, XRD, ICP–MS ကဲ့သို့အမျိုးမျိုးသော စမ်းသပ်မှုများနှင့် ခွဲခြမ်းစိတ်ဖြာမှုများ ပြုလုပ်ခဲ့ပါသည်။ ဓာတုစမ်းသပ်မှုနှင့် ခွဲခြမ်းစိတ်ဖြာမှုရလဒ်များအပေါ် အခြေခံ၍ Open–pit နှင့် Low–grade ore dump တို့မှကောက်ယူခဲ့သော စွန့်ပစ်ကျောက်နမူနာများတွင် အက်စစ်ဓာတ်ထွက်နိုင်သော ကျောက်များနှင့် Acid mine drainage ဖြစ်နိုင်သော အလားအလာရှိသည်ကိုဖော်ထုတ်တွေ့ရှိခဲ့ပါသည်။ Two–step batch leaching စမ်းသပ်မှုအရ အဆိုပါကျောက်နမူနာများတွင် Metal ions များဖြစ်သည့် As, Al, Fe, Cu, and $SO_4^{2-}$ များ ပျော်ဝင်နေပြီး pH တန်ဖိုး 4 ထက် လျော့နည်းနေသည်ကိုတွေ့ရှိရပါသည်။ အာဆင်းနစ်ပျော်ဝင်မှုသည် အခြား metal ions များ ပျော်ဝင်ခြင်းထက် အချိန်ကြာမြင့်စွာ ပျော်ဝင်နေနိုင်သည်ကိုတွေ့ရှိပါသည်။ ထို့ကြောင့် Acid Mine Drainage generation ဖြစ်မှုစေသည့် sulfides ဓာတ်တိုးမှုကို ထိန်းချုပ်ခြင်းနှင့် သတ္တုများပျော်ဝင်မှုအား လျှော့ချခြင်းကဲ့သို့သော သင့်လျော်သောအစီအမံများပြုလုပ်ရန် အလွန် အရေးကြီးပါသည်။

**Acid Mine Drainage and Its Characteristics at Kyaukpahto Gold Mine, Myanmar**

## 1. Introduction

Acid mine drainage (AMD) which is also known as acid rock drainage (ARD), causes environmental problems that affect many countries with historic or current mining activities. AMD is resulted from the exposure of sulfide ores and minerals to water and oxygen. When the ore is exposed to generate AMD, sulfate and heavy metals such as iron, copper, lead, nickel, manganese, cadmium, aluminium and zinc are also released to contaminate into that water (Moodley et al., 2017). Acidic, metals-rich waters may also form in spoil heaps, waste rocks and mine tailings, essentially by the same biologically reactions as in mine adits, shafts, pit-walls and pit-floors. Due to the more disaggregated (and more concentrated, in the case of tailings) nature of the acid-generating minerals in these waste materials, AMD that flows from them may be more aggressive than that discharges from the mine itself. Another important consideration is that it poses the potential long-term pollution problem as the production of AMD may continue for several years after mines was closed and tailing dams was decommissioned. (Johnson & Hallberg, 2005). The most common acid-generating sulfide minerals are enlisted as pyrite/marcasite ($FeS_2$), pyrrhotite (FeS), chalcopyrite ($CuFeS_2$) and arsenopyrite (FeAsS). In general, pyrite, the most common sulfide mineral of waste rocks and typical of many oxidation processes during weathering, is oxidized in accordance with the following reactions (Sengupta, 1993):

$$FeS_{2(s)} + \tfrac{7}{2}O_{2(g)} + H_2O_{(l)} \rightarrow Fe^{2+}{}_{(aq)} + 2SO_4{}^{2-}{}_{(aq)} + 2H^+{}_{(aq)} \tag{1}$$

If the surrounding environment is sufficiently oxidizing, much of the ferrous ion will oxidize to ferric ion:

$$Fe^{2+}{}_{(aq)} + \tfrac{1}{4}O_{2(g)} + H^+{}_{(aq)} \leftrightarrow Fe^{3+}{}_{(aq)} + \tfrac{1}{2}H_2O_{(l)} \tag{2}$$

At pH value above 2.3 to 3.5, the ferric iron will precipitate as $Fe(OH)_3$, leaving little $Fe^{3+}$ in solution while lowering pH at the same time:

$$Fe^{3+}{}_{(aq)} + 3H_2O_{(l)} \leftrightarrow Fe(OH)_{3(s)} + 3H^+{}_{(aq)} \tag{3}$$

Any $Fe^{3+}$ that does not precipitate from solution may be used to oxidize additional pyrite:

$$FeS_{2(s)} + 14Fe^{3+}{}_{(aq)} + 8H_2O_{(l)} \rightarrow 15Fe^{2+}{}_{(aq)} + 2SO_4{}^{2-}{}_{(aq)} + 16H^+{}_{(aq)} \tag{4}$$

Acid generation that produces iron which is eventually precipitates as Fe(OH)3 may be represented by a combination of reactions:

$$FeS_{2(s)} + \tfrac{15}{4}O_{2(g)} + \tfrac{7}{2}H_2O_{(l)} \rightarrow Fe(OH)_{3(s)} + 2SO_4{}^{2-}{}_{(aq)} + 4H^+{}_{(aq)} \tag{5}$$

The oxidation process could take place both in short- and long-term period, depending on many factors involved, and will release three main chemical parameters that could influence water quality: sulphate concentration (as messenger of sulfide oxidation), acidity, and dissolved metals.

AMD can be prevented and its prevention consists of several methods. Generally, the purpose of the AMD prevention is the minimization of AMD factors. These factors include oxygen supply, water infiltration and leaching, sulfide mineral availability and bacteria (related to biogeochemical process). Moreover, in the prevention method, maximizing the availability of acid neutralizing minerals or increasing the infiltrated water pH could be an option (Lottermoser, 2010).

The Kyaukpahto gold mine, the first open-pit gold mine in Myanmar, is located about 30 km east of the Kawlin Township and 250 km north of the Mandalay, in northern Myanmar (Figure 1). Exploration works and calculations of ore reserves at Kyaukpahto have been conducted since 1982. By the 1990s, a total of 318 holes had been drilled and the reserves were estimated at approximately 6 million tons at an average grade of 3.0 g/t Au with a cut-off grade of 1.0 g/t (Saw Maung et al., 1991). The important ore minerals associated with gold mineralization are pyrite, arsenopyrite and chalcopyrite with minor amounts of other sulfides. Gold occurs as free particles or locked up in the sulfides such as pyrite, arsenopyrite, chalcopyrite and tetrahedrite (Swe, Y. M, 2004).

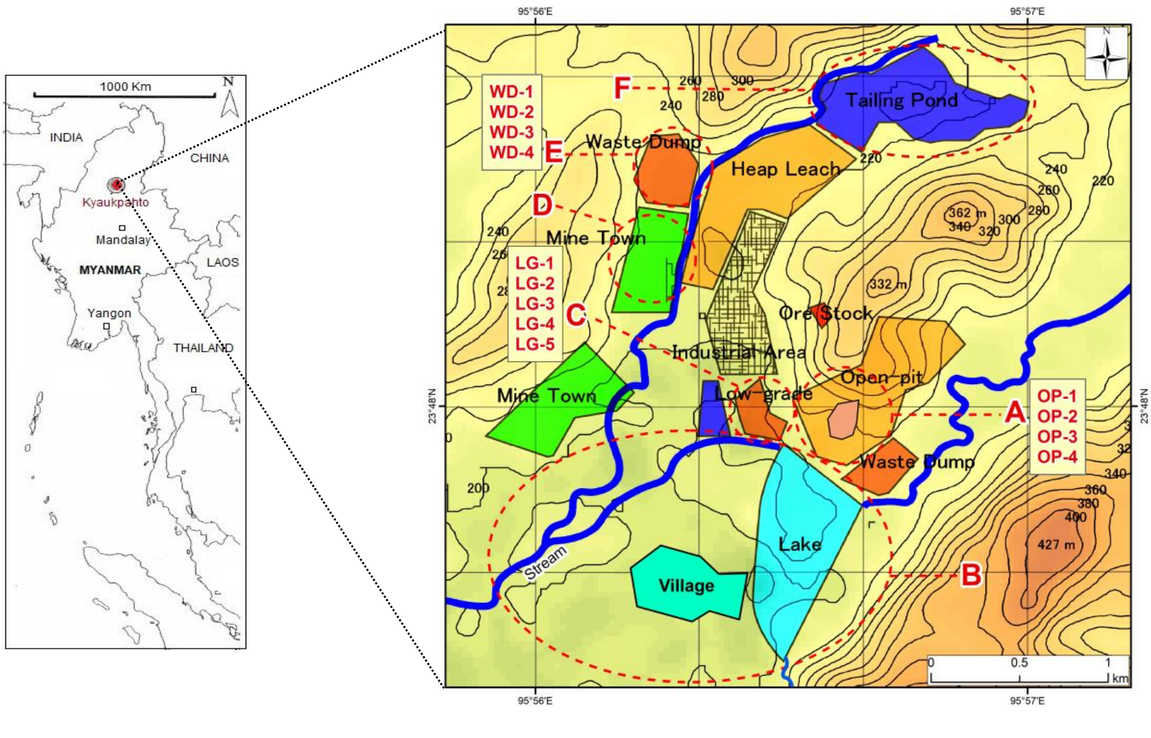

Figure 1. Location map of Kyaukpahto gold mine: red letters indicate Water-sampling areas; Open-pit (OP), Low-grade ore dump (LG), and Waste dump (WD) indicate waste rock sampling areas.

## 2. Objectives

In Kyaukpahto gold mine, gold ore were exploited by open-pit mining and waste rocks were disposed at waste dumps near the open pit mine site. A huge amount of waste rocks containing metal sulfides, such as pyrite, chalcopyrite, were exposed to the surface, favoring the metal sulfides in reaction with air and water, and produced acidic mine water. High values of hardness and heavy metal concentrations were observed in mine water which apparently reduce the quality of water and create potential threat to nearby environment. This work focuses to address the potential AMD-generation by waste rocks in that gold mine and identify the acid-generating waste rocks and non-acid forming waste rocks.

## 3. Materials and Methods

Field investigation was carried out in Kyaukpahto gold mine during January 2019 in order to understand the field conditions in mining area with respect to waste rocks. Rock samples were taken from three locations (here named as area A, C and E) from mine site area. Paste pH test, Net Acid Generating (NAG) test, Acid Base Accounting (ABA) test, and X-ray Fluorescence (XRF) analysis were performed in order to understand the conditions of waste rocks and mine waters from the Kyaukpahto gold mine area. Acidic water with red-brick color was found in the open-pit and low-grade ore dump (Figure 2) and basically the water flow is north to south.

(a) Pit water (b) Open-pit (c) Low-grade ore dump

Figure 2. Field photos showing AMD generation in open-pit and low-grade ore dump.

In paste pH test, rock samples were dissolved with de-ionized water after pulverization of the samples. The change of pH was reported as paste pH after 12 hours of the dissolution process. Rock samples were dissolved with $H_2O_2$ by forced oxidation process in

NAG test. The potential of acid producing of samples were quantified on the basis on the change of pH which was reported as NAG pH after the dissolution process. NAG pH indicated the change of water quality when the rock samples were dissolved completely. The measured result of NAG pH indicates the net acid and/or base left in the rock sample after the acid producing and consuming occurred. Furthermore, after all of the reaction happens back-titrating to the pH 4.5 and 7.0 was carried out in order to know the residual acid amount. This value was expressed in unit kg $H_2SO_4$/t. The balance of acid producing capacity and potential of neutralization of rock sample were calculated based on Maximum Potential Acidity (MPA) and Acid Neutralizing Capacity (ANC) in ABA test (Sobek et al., 1978). MPA was calculated based on total sulfur content whereas ANC was calculated through titration process with hydrochloric acid.

Standardized batch leaching tests were conducted to study the leaching properties of metals from waste rocks. Two-steps sequential leaching procedure, based on CEN prEN 12457-3, was adopted to discuss the dissolution behavior of metals under the different L/S ratio and contact time. The pulverized rock samples were dissolved with a rotation of 200 rpm under the L/S = 2 for the first step and the L/S = 8 for the second step. The duration of rotation was 6 and 18 hours for the first and second step, respectively. The water samples from batch leaching tests were measured for pH, EC heavy metals by ICP-MS Agilent 7500 Series after filtered through 0.45 mm filters. In addition, the percentage of total sulfur, as a represented-number of acid potential, was obtained from XRF analysis using a Rigaku RIX 3100 machine. The value of the balance was calculated as Net Acid Producing Potential (NAPP). This value was utilized as an indicator of acid producing capacity in rock during mining operation. Based on the MPA and ANC results, NAPP was calculated by acid–base balance calculation method from the formula NAPP (kg $H_2SO_4$/t) = MPA – ANC. Geochemical analyses, were conducted with reference to the standard proposed by AMIRA (AMIRA, 2002). All the research works were performed at Department of Earth Resources Engineering, Kyushu University.

## 4. Results and Discussion

NAG test indicated that two samples have NAG pH $\geq$ 4.5 and 11 samples have NAG pH < 4. Furthermore, combined these NAG values with the values of NAPP calculation, the classification of 13 rock samples collected from Open pit, Low grade ore dump and waste dump are summarized in Table 1. Paste pH indicates pH when reacted with water, but is an index to predict the occurrence of acid water (pH=4) in the present due to the reaction of the sulfide minerals contained in the rock sample, such as OP-2, OP-4, and LG-1. Rocks are classified as PAF if the NAG pH ≤ 4.5 and the NAPP ≥ 0 kg $H_2SO_4$ (AMIRA, 2002). The more positive NAPP values of rock indicates the higher capacity in producing acid while a more negative value informing that less capacity in producing acid and higher capacity in neutralizing the acidity within the system.

Table 1 Geochemical test results of rock samples.

| Location | Sp. ID | Paste pH | Paste EC (ms/cm) | MPA* | ANC* | NAPP* | NAG pH | Geochem Class |
|---|---|---|---|---|---|---|---|---|
| Area - A (Open-pit) | **OP-1** | 5.10 | 1.17 | 11.9 | 0.84 | 11 | 2.97 | PAF |
| | **OP-2** | 3.90 | 3.00 | 55.6 | 2.03 | 54 | 2.40 | PAF |
| | **OP-3** | 5.20 | 2.10 | 79.3 | 2.99 | 76 | 2.05 | PAF |
| | **OP-4** | 4.40 | 1.52 | 35.5 | 2.94 | 33 | 2.57 | PAF |
| Area -C (Low grade ore dump) | **LG-1** | 3.60 | 2.10 | 18.5 | 0.84 | 18 | 3.27 | PAF |
| | **LG-2** | 6.10 | 1.06 | 31.5 | 1.80 | 30 | 3.05 | PAF |
| | **LG-3** | 7.00 | 1.07 | 51.7 | 0.60 | 51 | 2.33 | PAF |
| | **LG-4** | 6.40 | 1.27 | 31.1 | 0.48 | 31 | 2.90 | PAF |
| | **LG-5** | 6.20 | 1.49 | 35.6 | 2.28 | 33 | 2.68 | PAF |
| Area - E (Waste Dump) | **WD-1** | 8.10 | 1.81 | 62.3 | 51.50 | 11 | 5.54 | **UC** |
| | **WD-2** | 7.80 | 3.90 | 150.2 | 9.70 | 140 | 2.00 | PAF |
| | **WD-3** | 8.70 | 1.08 | 21.7 | 55.56 | -34 | 8.49 | **NAF** |
| | **WD-4** | 7.80 | 2.70 | 107.8 | 2.04 | 106 | 2.03 | PAF |

*** in kg $H_2SO_4$/ton**
MPA: Maximum Potential Acidity
ANC : Acid Neutralizing Capacity
NAPP: Net Acid Potential Production
NAG : Net Acid Generating

**Calculation:**
MPA = Total S% * 30.6
NAPP = MPA – ANC

**Classification:**
NAF: NAG pH ≥ 4.5; NAPP ≤ 0
PAF: NAG pH < 4.5; NAPP > 0
PAF: Potential Acid Forming
NAF: Non Acid Forming
UC: Uncertain

The results indicated that only one sample (sample WD-1 with NAG pH= 5.54, NAPP= 10.78 kg $H_2SO_4$/ ton) was identified as "UC" (uncertain) and that was probably due to the conflict of NAG pH and NAPP values. However, the overall result in classification indicated that NAG test was sufficient to classify most of the waste rocks as PAF (except one sample from Area E). The possibility of acid water generation at the present open pit and low grade ore dump but waste dump rock samples has ANC indicating the neutralization capacity of the acid is large compared with other rock samples, it can be seen that the possibility of occurrence of acidic water is classified as low NAF and UC . In general, the results indicated that Area E contain both NAF and PAF materials, whereas Area A and C have only PAF materials. The presence of PAF particularly indicated the potency of AMD generation from the locations where the samples were collected.

The XRF analysis results of rock samples, as shown in Table 2, it can be seen that the sample OP-3 collected at open pit contains a high concentration of arsenic. In addition, the Mg content and the Ca content of the samples of WD-1 and WD-3 classified as NAF and UC are larger than those of other samples. Considering that the ANC showing the neutralizing ability of WD-1 and WD-3 is larger than the other samples, carbonate minerals are presumed to be presented in both samples.

Table 2 XRF analysis results of analyzed samples from three locations.

| **Location** | **Sp. ID** | **$SiO_2$ mass %** | **$Al_2O_3$ mass %** | **FeO mass %** | **MnO mass %** | **MgO mass %** | **CaO mass %** | **S mass %** | **Cu ppm** | **Au ppm** | **As ppm** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Area -A (Open-pit) | **OP-1** | 93.4 | 2.86 | 0.85 | 0.001 | 0.12 | 0.02 | 0.39 | 8 | 21 | 5691 |
| | **OP-2** | 78.78 | 10.06 | 2.32 | 0.004 | 0.35 | 0.03 | 1.82 | 69 | 29 | 852 |
| | **OP-3** | 73.96 | 9.51 | 4.62 | 0.002 | 0.43 | 0.01 | 2.59 | 8 | 14 | 23524 |
| | **OP-4** | 85.14 | 7.22 | 1.56 | 0.002 | 0.28 | 0.03 | 1.16 | 45 | 25 | 249 |
| Area -C (Low-grade ore dump) | **LG-1** | 87.32 | 6.95 | 0.72 | 0.001 | 0.23 | 0.02 | 0.60 | 5 | 32 | 169 |
| | **LG-2** | 84.80 | 7.45 | 1.46 | 0.004 | 0.44 | 0.05 | 1.03 | 205 | 16 | 426 |
| | **LG-3** | 83.82 | 6.27 | 2.37 | 0.004 | 0.49 | 0.07 | 1.69 | 201 | 31 | 826 |
| | **LG-4** | 81.25 | 9.38 | 1.56 | 0.005 | 0.60 | 0.03 | 1.016 | 112 | 19 | 293 |
| | **LG-5** | 79.79 | 9.90 | 1.79 | 0.005 | 0.68 | 0.04 | 1.16 | 64 | 26 | 506 |
| Area - E (Waste Dump) | **WD-1** | 67.19 | 12.82 | 4.35 | 0.085 | 1.44 | 2.25 | 2.04 | 0 | 22 | 404 |
| | **WD-2** | 61.46 | 11.82 | 7.56 | 0.03 | 1.10 | 1.24 | 4.91 | 4 | 23 | 910 |
| | **WD-3** | 67.27 | 13.46 | 4.03 | 0.136 | 2.22 | 2.68 | 0.71 | 3 | 26 | 90 |
| | **WD-4** | 66.08 | 12.83 | 5.95 | 0.028 | 1.31 | 0.36 | 3.52 | 2 | 28 | 637 |

The result of the two-step batch test, as shown in Table 3, the elution amount (mg / kg) of the element eluted per unit weight of the rock sample. In geochemical test results of rock, the PAF rocks classified both 1$^{st}$ step and 2$^{nd}$ step, the acidic water around pH = 4 generates for both first and second step from the rock samples of OP-2, OP-3, OP-4, LG-1, LG-2, LG-3, LG-4, LG-5 and WD-4 which are classified as PAF. A lot of metals and sulphate ions are dissolved under the acidic conditions in the first step: aluminum (0.86~68.7 mg/kg), manganese (0.48~22.0 mg/kg), iron (6.1~78.8 mg/kg), copper (0.07~1.65 mg/kg), arsenic (0.02~26.11 mg/kg), sulphate ion (489~7303 mg/kg) for OP-1, OP-2, OP-3, OP-4, LG-1, LG-2, LG-3,LG-4, LG-5 and WD-4.

Table 3 Result of two-step batch test (elution amount of element eluted per unit weight of rock sample).

| **Step** | **Location** | **Sample** | **pH** | **EC mS/cm** | **Al mg/kg** | **Mn mg/kg** | **Fe mg/kg** | **Cu mg/kg** | **As mg/kg** | **$SO_4^{2-}$ mg/kg** |
|---|---|---|---|---|---|---|---|---|---|---|
| | **MNEQ* guidelines (2015)** | | **6-9** | **-** | **-** | **-** | **2** | **0.3** | **0.1** | **-** |
| **First step** | Area –A (Open pit) | OP-1 (L/S = 2) | 5.08 | 0.93 | 1.13 | 0.77 | 6.1 | 0.11 | 1.35 | 489 |
| | | OP-2 (L/S = 2) | 4.03 | 2.0 | 40.16 | 0.98 | 32 | 1.12 | 0.02 | 2320 |
| | | OP-3 (L/S = 2) | 4.73 | 2.1 | 0.86 | 0.48 | 6.7 | 0.07 | **26.11** | 1205 |
| | | OP-4 (L/S = 2) | 4.15 | 1.51 | 20.02 | 1.05 | 36.1 | 0.1 | 0.32 | 1374 |
| | **Area - C** (Low-grade ore dump) | LG-1 (L/S = 2) | 4.18 | 0.91 | 13.19 | 0.32 | 6.2 | 0.16 | 0.11 | 774 |
| | | LG-2 (L/S = 2) | 4.23 | 1.96 | 29.54 | 2.28 | 12.2 | 1.31 | 0.09 | 2217 |
| | | LG-3 (L/S = 2) | 4.08 | 2.0 | 68.74 | 1.3 | 30.9 | 1.65 | 0.14 | 2837 |
| | | LG-4 (L/S = 2) | 4.36 | 2.4 | 20.29 | 1.16 | 6.7 | 0.91 | 0.05 | 2481 |
| | | LG-5 (L/S = 2) | 4.28 | 2.5 | 35.42 | 1.07 | 9.7 | 0.49 | 0.10 | 2673 |
| | **Area - E** Waste dump | WD-1 (L/S = 2) | 7.87 | 1.83 | 0.69 | 0.05 | 0.6 | 0.09 | 0.10 | 1384 |
| | | WD-2 (L/S = 2) | 7.39 | 3.1 | 1.88 | 0.54 | 1 | 0.14 | 0.12 | 354 |
| | | WD-3 (L/S = 2) | 8.18 | 0.92 | 0.65 | 0 | 0.6 | 0.12 | 0.06 | 310 |
| | | WD-4 (L/S = 2) | 4.23 | 4.8 | 27.57 | 22.07 | 78.8 | 0.1 | 0.12 | 7303 |
| **Second step** | **Area - A** (Open pit) | OP-1 (L/S = 2~10) | 5.42 | 0.20 | 2.35 | 0.21 | 1.4 | 0.06 | 5.70 | 65 |
| | | OP-2 (L/S = 2~10) | 4.12 | 0.57 | 9.49 | 0.13 | 6.1 | 0.35 | 0.01 | 389 |
| | | OP-3 (L/S = 2~10) | 5.23 | 0.63 | 0.33 | 0.06 | 1.3 | 0.03 | **27.23** | 218 |
| | | OP-4 (L/S = 2~10) | 4.26 | 0.48 | 10.01 | 0.14 | 12.01 | 0.07 | 0.069 | 306 |
| | **Area - C** | LG-1 (L/S = 2~10) | 4.29 | 0.28 | 3.96 | 0.03 | 1.65 | 0.05 | 0.04 | 142 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| (Low-grade ore dump) | LG-2 (L/S = 2~10) | 4.41 | 0.44 | 6.07 | 0.26 | 4.14 | 0.22 | 0.04 | 263 |
| | LG-3 (L/S = 2~10) | 4.17 | 0.58 | 14.27 | 0.17 | 8.7 | 0.47 | 0.05 | 373 |
| | LG-4 (L/S = 2~10) | 4.44 | 0.67 | 3.80 | 0.18 | 1.01 | 0.25 | 0.01 | 390 |
| | LG-5 (L/S = 2~10) | 4.41 | 0.72 | 4.86 | 0.15 | 3.15 | 0.18 | 0.05 | 422 |
| **Area - E** (Waste dump) | WD-1 (L/S = 2~10) | 8.15 | 0.58 | 0.62 | 0.07 | 0.91 | 0.07 | 0.15 | 213 |
| | WD-2 (L/S = 2~10) | 7.36 | 1.69 | 0.36 | 0.24 | 0.34 | 0.06 | 0.09 | 720 |
| | WD-3 (L/S = 2~10) | 8.65 | 0.35 | 0.5 | 0 | 0.32 | 0.06 | 0.11 | 53 |
| | WD-4 (L/S = 2~10) | 4.20 | 1.53 | 6.8 | 4.17 | 30.5 | 0.05 | 0.08 | 90 |

The leached amount under the neutral conditions shows quite lower values compared to acidic conditions in the first step: aluminum (0.65~1.88 mg/kg), manganese (0~0.54 mg/kg), iron (0.6 ~1 mg/kg), copper (0.09~0.14 mg/kg), arsenic (0.06~0.12 mg/kg), and sulphate ion (310~1384 mg/kg) for WD-1, WD-2, and WD-3. High As can be seen in OP-3 and OP-1 rock samples. The elution amount from the sample OP -3 containing a large amount of As in the rock is found to be the largest. Also in Al, Fe, Cu, Zn which showed excessive elution in the acidic environment in the 1$^{st}$ step, the elution amount in the 2$^{nd}$ step was largely reduced, but As eluted from OP-3 did not decrease in the second stage. This indicates that As eluted from rocks containing a large amount of As such as OP-3 may elute over a long term compared to other metal ions. Therefore, the countermeasures to minimize AMD generation for long term considering the dissolution behavior of As have to be discussed in Kyaukpahto gold mine.

## 5. **Conclusion**

In this study, the potential generation of AMD is considered to be occurred at the Kyaukpahto gold mine. The current mine managements are performed with preventive efforts to avoid the formation of acidic water, and with treatment of acidic water that has been occurred in the mine area. The results the chemical tests and analyses indicated that waste dump (Area E) contain both NAF and PAF materials. The presence of PAF particularly indicated the potency of AMD generation from the locations where the samples were collected. The problems of AMD generation at Kyaukpahto gold mine are considered to be existed at active pits, and low grade ore dump. Concentrations of toxic chemical elements (e.g. Fe, As, etc.) are very high in the acidic mine waters from the pit. Additionally, the result also indicated that there is a possibility to dissolve arsenic for long term from the waste rocks which contains a lot of arsenic may elute than other metal ions. Moreover, the results of NAG and two-step sequential leaching tests indicate a potential As-bearing AMD contamination risk in the future in the waste dump area, through the quality of its wastewater indicates that there is currently no AMD there. In conclusion, to ensure the sustainable development of resources at this mine, long-term contamination of wastewater by As and metal dissolutions should be considered in AMD prevention measures regardless of the evidence for AMD at the present time.

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