

**HYDROGEOCHEMISTRY OF ROCK-WATER
INTERACTION AND WATER QUALITY
AROUND BUKIT MANTRI, BALUNG, TAWAU,
SABAH**



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UMS
UNIVERSITI MALAYSIA SABAH

**FACULTY OF SCIENCE AND NATURAL
RESOURCES**

UNIVERSITI MALAYSIA SABAH

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**DISSERTATION SUBMITTED IN FULFILMENT
OF THE REQUIREMENTS FOR THE DEGREE
OF MASTERS OF SCIENCE**

**FACULTY OF SCIENCE AND NATURAL
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UNIVERSITI MALAYSIA SABAH

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IJAZAH : **SARJANA**

BIDANG : **GEOLOGI**

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DECLARATION

I hereby declare that the material in this thesis is my own except for quotations, equations, summaries and references, which have been duly acknowledged.

18 JANUARI 2023



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Dr. Sanudin bin Tahir

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Mohd Shafreen bin Mad Isa

18 January 2023

ABSTRACT

A study was carried out to characterise the geology, geochemistry, and mineralogy of hydrothermally altered andesite host to a gold mineralization system in Bukit Mantri area, Balung, Tawau. The main objective is to determine the hydrogeochemical composition, the status of water quality in waters draining the area; and to evaluate the potential of environmental degradation of mining. Geology of the study area is mainly delineated by the andesite country rocks. The andesite has been hydrothermally altered, and among the alteration profiles are argillic, propylitic, silicic, and sulfuric. Geochemical analysis shows that SiO₂ concentration is relatively higher in silicified andesite, K₂O in propylitized andesite, and SO₃ in sulfidized andesite. Moreover, the hydrothermal alterations also increased the concentration of trace elements in the andesite, such as As, Cu, Pb and Zn. As, Pb and Zn also found enriched in the volcanic breccia. Analyses on mineralogy show that quartz is the predominant mineral, followed by pyrite, and the hydrothermal fluids have introduced and enriched chlorite and K-feldspar in propylitized andesite, while acid leaching has caused the formation of clay minerals such as kaolinite and introduced muscovite in the argilized andesite. Pyrite found in the altered andesite strongly correlates with the concentration of SO₃, implying higher acidity generation potential. On the other hand, analyses of the waters suggest that the water quality in the area is fresh, circumneutral, and has low redox potential, electrical conductivity, and dissolved solids. In the waters, the major cations and anions according to their dominancy order are Ca²⁺>Mg²⁺>K⁺>Na⁺, and SO₄²⁻>HCO₃⁻>Cl⁻, respectively, whereas Na⁺>K⁺ and HCO₃⁻>SO₄²⁻ are observed when under the influence of precipitation. Waters are classified into Ca-SO₄ and mix types in mineralised sources drainages of Bukit Mantri andesite, and in Sungai Mantri, respectively. However, both are in CaMg-HCO₃ type owing to weathering and excess of silicate minerals. The hydrogeochemistry of these waters is mainly attributed to the weathering of sulphides such as sulphide minerals, which intensifies closer to the mineralized area. The weathering of silicate minerals provides a sufficient buffer in these waters and retains them within circumneutral pH. The solubility of constituents is relatively low, in the descending order of Fe > Al > Mn > Zn > Ag > Ba > Pb > Cr > Cu > Co > Ni > Cd > As. Substantial changes in the solubility of these metals have been observed for Fe, Al, Mn, and Zn, associated with the relatively higher concentration in country rocks in the Bukit Mantri area and under the influence of mine development activities. The geoenvironmental model highlights the rock-water interaction and the result shows a possible deterioration of the water body due to increased acidity and higher metal constituents following mining activity if no mitigation measures are in place.

ABSTRAK

HIDROGEOKIMIA INTERAKSI BATUAN-AIR DAN KUALITI AIR SEKITAR BUKIT MANTRI, BALUNG, TAWAU, SABAH

Kajian telah dijalankan untuk mencirikan geologi, geokimia dan mineralogi batuan perumah andesit yang terubah secara hidroterma yang dikaitkan dengan pemineralan emas dan batuan piroklas di kawasan Bukit Mantri, Balung, Tawau. Objectif utama kajian ini ialah menentukan komposisi hidrogeokimia, status kualiti air saliran di kawasan tersebut; dan menilai hubung kait interaksi batu-air dan menilai potensi degradasi alam sekitar kesan aktiviti perlombongan. Geologi kawasan kajian terdiri daripada batuan perumah andesit. Batuan andesit ini telah berubah secara hidroterma dan antara perubahan pada profil ialah argilik, propilik, silisik dan sulfidik. Analisis geokimia menunjukkan bahawa kepekatan SiO_2 secara relatifnya lebih tinggi dalam andesit tersilisik, K_2O dalam andesit terpropil, dan SO_3 dalam andesit tersulfida. Selain itu, perubahan hidroterma juga meningkatkan kepekatan unsur surih dalam andesit, seperti As, Cu, Pb dan Zn. Unsur As, Pb dan Zn juga didapati signifikan dalam batuan vulkanik. Analisis mineralogi menunjukkan bahawa kuarza adalah mineral utama diikuti oleh pirit, dan cecair hidroterma telah menghasilkan dan memperkayakan klorit dan K-feldspar dalam batuan andesit terpropil, manakala pelarutan asid menyebabkan pembentukan mineral lempung seperti kaolinit dan memperkenalkan muskovit dalam andesit terargilik. Mineral pirit yang terdapat dalam andesit yang terubah berkorelasi dengan kepekatan SO_3 , menunjukkan potensi penjanaan keasidan yang lebih tinggi. Sebaliknya, analisis ke atas saliran menunjukkan bahawa, kualiti air di kawasan tersebut adalah segar, hampir neutral dan mempunyai potensi tindak balas redoks, kekonduksian elektrik dan pepejal terlarut yang rendah. Dalam saliran, kation dan anion utama mengikut susunan dominasinya ialah $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+ > \text{Na}^+$, and $\text{SO}_4^{2-} > \text{HCO}_3^- > \text{Cl}^-$, manakala $\text{Na}^+ > \text{K}^+$ dan $\text{HCO}_3^- > \text{SO}_4^{2-}$ diperhatikan apabila berada di bawah pengaruh kerpasan. Saliran dikelaskan kepada Ca- SO_4 dan jenis campuran dalam saliran daripada batuan andesit yang dipengaruhi pemineralan di Bukit Mantri, dan di Sungai Mantri, masing masing. Walau bagaimanapun, kedua-duanya adalah dalam jenis CaMg- HCO_3 disebabkan oleh luluhawa dan lebihan mineral silikat. Hidrogeokimia saliran ini terutamanya luluhawa sulfida seperti mineral sulfida meningkat lebih dekat dengan kawasan pemineralan. Namun, luluhawa mineral silikat menyediakan penampungan yang mencukupi di saliran ini dan mengekalkannya dalam pH hampir neutral. Keterlarutan unsur surih adalah agak rendah, dan dalam tertib menurun $\text{Fe} > \text{Al} > \text{Mn} > \text{Zn} > \text{Ag} > \text{Ba} > \text{Pb} > \text{Cr} > \text{Cu} > \text{Co} > \text{Ni} > \text{Cd} > \text{As}$. Perubahan ketara dalam keterlarutan unsur-unsur surih ini telah diperhatikan ke atas Fe, Al, Mn dan Zn, yang dikaitkan dengan konsentrasinya yang tinggi dalam batuan perumah andesit di kawasan Bukit Mantri dan di bawah pengaruh aktiviti pembangunan lombong. Model geosekitaran menggambarkan interaksi batuan-air dan dapatan kajian menunjukkan kemungkinan berlakunya kemerosotan kualiti saliran disebabkan peningkatan keasidan dan unsur unsur surih yang lebih tinggi berikutan aktiviti perlombongan jika tiada langkah mitigasi dilaksanakan.

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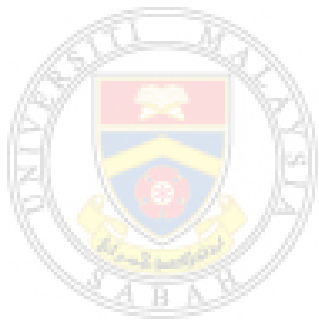
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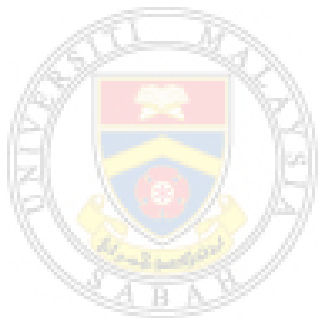
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LIST OF ABBREVIATIONS

Ha	-	Hectare
m	-	Meter
a.m.s.l.	-	Above Mean Sea Level
DID	-	Department of Irrigation and Drainage
AMD	-	Acid Mine Drainage
WHO	-	World Health Organization
DOE-WQI	-	Department of Environment – Water Quality Index
g/t	-	Gramme per Tonne
mg/L	-	Milligram per Litre
EC	-	Electrical Conductivity
Eh	-	Oxidation-Reduction Potential
DO	-	Dissolved Oxygen
TDS	-	Total Dissolved Solids
°C	-	Degree Celcius
°F	-	Degree Fahrengit
°K	-	Degree Kelvin
°R	-	Degree Rankine
µS/cm	-	Mircosiemens per Centimetre
mV	-	Milivolts
SEIA	-	Special Environmental Impact Assessment
GPS	-	Global Positioning System
DSLR	-	Digital Single-Lens Reflect
LLC	-	Limited Liability Company
HNO₃	-	Nitric Acid
ICP-OES	-	Inductively Coupled Plasma Optical Emission Spectrum
ppm	-	Parts per Million, pp48
µm	-	Micrometer
APHA	-	American Public Health Association
HCL	-	Hydrochloric Acid

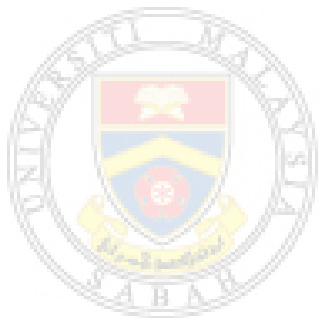
XRF	-	X-Ray Fluorescence
wt%	-	Weight Per Cent
XRD	-	X-Ray Diffraction
JCPDS	-	Joint Committee on Powder Diffraction Standards
INWQS	-	Interim National Water Quality Standard pp64
NTU	-	Nephelometric Turbidity Units
ID	-	Identification Number
Alt	-	Altitude
FeO^T	-	Total Iron as FeO
LOI	-	Loss of Ignition
n.m.	-	Not Measured
n.d.	-	Not Detected
DIC	-	Dissolved Organic Carbon



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CHAPTER 1

INTRODUCTION

1.1 Introduction

Mineral resource extraction has begun in Bukit Mantri, Tawau, Sabah, within 946.4 hectares (Ha) in Gunung Wullersdorf Forest Reserve and Ulu Kalumpang Forest Reserve with the approval of the respective authorities. The lease for the mining was issued for thirty-five years, primarily for gold, in 2013. The associated metal ores are copper and silver.

While economic mineral deposits are typically thought to be exploited, contributing to the supply of raw materials to various industries, employment creation, encouraging infrastructure development, support services, and economic opportunities, the experience and lessons learned from other mining activities have provided some insights into the need to consider the possibility of environmental degradation caused by mineral resources extraction.

Before the start of mining activities in Bukit Mantri, the only mine that ever operated in Sabah was copper mining in Mamut, near Ranau. This mine was forced to close about two decades ago due to uneconomic operations resulting from lower metal prices and landslide occurrences (Shin, 2000). What is known is that this former mine, along with other abandoned and still-in-operation mines elsewhere in Malaysia, have been reported to be the source of various environmental issues, particularly with water bodies.

Since mining activity constantly exposes and discards nonvaluable minerals such as pyrite and various metal-bearing minerals, the weathering processes may

cause environmental degradation. Thus, in this study, the concept of rock-water interaction is applied to assess the potential for environmental degradation during and after mining, particularly in water bodies near Bukit Mantri area. In this regard, the study will investigate the geology and mineralisation occurrence in the area, the geochemistry and mineralogy of the host rock and the hydrogeochemical characteristics of the water bodies. Understanding the rock-water interaction in Bukit Mantri mineralised area is crucial for predicting environmental degradation caused by mining activities and developing effective mitigation strategies.

1.2 Objectives

The study intends to –

- a) Identify geological background and mineralisation occurrence in the study area, as well as characterise geochemical composition and mineralogy of the hydrothermally altered country rocks;
- b) Characterise hydrogeochemical composition of the waters draining in the study area.
- c) evaluate the influence of the rock-water relationship on the hydrogeochemical status of waters and the potential environmental degradation of mining.

1.3 Background of Study Area

1.3.1 Location of the Study Area

Bukit Mantri mineral deposit and the mining lease area are surrounded by Gunung Wullersdorf and Ulu Kalumpang Forest Reserves, near Balung, District of Tawau, Sabah. Geographically, the mine is situated at 4°29'48.58"N and 118° 6'15.11"E, some 37 kilometres northeast of Tawau. The location of the mineralised area is shown in Figure 1.1.