GEOLOGY AND BIOGEOCHEMICAL STUDY IN SOKOR, KELANTAN

by

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A thesis submitted in fulfilment of requirements for the degree of Bachelor of Applied Science (Geoscience) with Honours

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DECLARATION

I declare that this thesis entitled "GEOLOGY AND BIOGEOCHEMICAL STUDY IN SOKOR, KELANTAN" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

"I hereby declare that I have read this thesis and in my

opinion this thesis is sufficient in terms of scope and quality for the

award of the degree of Bachelor of Applied Science (Geoscience) with Honors"

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Date : …………………………………..

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Geology and Biogeochemical Study in Sokor, Kelantan

ABSTRACT

Biogeochemistry is a multidisciplinary field that studies the complex relationship between geological and biological components. This research investigated the relationship of plants with ore elements in term of geochemistry and mineralogy. Geological mapping had been carried out: the identified lithology of the study area with 25 kilometres squared is argillaceous and calcareous units and the geological structures of folding which contribute to the current bed dipping and hydrothermal alteration through joint infilling has indicated an ore deposit region. In preliminary study, seven sets of soil samples were collected and analysed through Atomic Absorption Spectrophotometer to scope down the study area. Four sets of soil and plant samples had been collected and characterized through Fourier-Transform Infra-Red Spectroscopy, X-ray methods (X-Ray Diffraction and X-Ray Fluorescence) and Inductively Coupled Plasma Mass Spectrometry respectively. The main composition of soil is clay minerals, kaolinite, dickite and pyrophyliite which can indicate argillic alteration and possible supergene enrichment for ore deposition. Phyllic alteration has also been found in area close to the study area with mineral assemblage of pyrite, quartz and sericite. There is also a relationship between the geomorphology, plant morphology and the ore element content in the soil: metal elements concentration is higher in lower elevation except aluminium and iron; the differential morphology of *Melastoma malabathricum* can indicate iron concentration in the soil. The findings of this research will be useful for diversifying current mineral exploration method in general and providing database for further investigation in the study area in specific.

Keywords: Biogeochemistry; Gold Indicator; Plant; Sokor; Kelantan; Geology

Geologi dan Kajian Biogeokimia di Sokor, Kelantan

ABSTRAK

Biogeokimia adalah bidang multidisiplin yang mengkaji hubungan kompleks antara komponen geologi dan biologi. Kajian ini menyiasat hubungan tumbuhan dengan unsur bijih dari segi geokimia dan mineralogi. Pemetaan geologi telah dijalankan dan lithologi kawasan kajian dengan keluasan 25 kilometer persegi dikenalpasti sebagai unit argilik dan kapur dan struktur geologi lipatan yang menyumbang kepada kemiringan semasa dan alterasi hidroterma yang menunjukkan kawasan berkenaan mengandungi bijih. Dalam kajian awal, tujuh set sampel tanah dikumpulkan dan dianalisis melalui Spektrometer Penyerapan Atom untuk mengecilkan kawasan kajian. Empat set sampel tanah dan tumbuhan telah dikumpulkan dan dicirikan melalui Spektroskopi Transformasian Fourier Infra-Merah (FTIR), kaedah X-ray (Difraksi X-Ray dan Pendarfluor X-Ray) dan Spektrometri Jisim Plasma Gandingan Aruhan (ICP-MS). Komposisi utama dalam tanah ialah mineral tanah liat, kaolinit, dikit dan porfilit yang menunjukkan alterasi argilik dan berkemungkinan pengayaan supergen bagi endapan bijih. Alterasi filit juga telah ditemui berdekatan dengan kawasan kajian melalui kumpulan mineral pirit, kuarza dan serisit. Terdapat hubungan antara geomorfologi, morfologi tumbuhan dan kandungan unsur bijih di dalam tanah: kepekatan unsur logam adalah lebih tinggi di ketinggian rendah kecuali aluminium dan besi; perbezaaan morfologi *Melastoma malabathricum* dapat menunjukkan kepekatan besi tanah yang berbeza. Penemuan kajian ini akan berguna bagi mempelbagaikan kaedah penerokaan mineral secara am dan membekalkan pangkalan data untuk penyelidikan lanjut di kawasan kajian secara spesifik.

Kata Kunci: Biogeokimia; Penunjuk Emas; Tumbuhan; Sokor; Kelantan; Geologi

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LIST OF ABBREVIATIONS

N	North
E	East
S	South
W	West
Au	Gold
Ag	Silver
As	Arsenic
Al	Aluminium
Fe	Iron
Zn	Zinc
Pb	Lead
Mn	Manganese
Cu	Copper
O	Oxygen
Si	Silicon
K	Potassium
Ti	Titanium
Ba	Barium
Ni	Nickel

Cr	Chromium
V	Vanadium
SiO_2	Silicon dioxide
sp.	Species
AAS	Atomic Absorption Spectrometry
FTIR	Fourier-Transform Infra-Red Spectroscopy
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence Spectrometry
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
LOI	Loss on Ignition
HNO_3	Nitric Acid
HCl	Hydrochloric Acid
H_2SO_4	Sulphuric Acid
H_2O_2	Hydrogen Peroxide
HF	Hydrofluoric Acid
$HClO_4$	Perchloric Acid
$LiBO_2$	Lithium Metaborate
$NaBO_3 \cdot {}_nH_2O$	Sodium Perborate
GIS	Geographic Information System
GPS	Global Positioning System
2D	Two Dimensional

3D	Three Dimensional
LTC or TLC	Latex Timber Clone
m	Metre
cm	Centimetre
pm	Millimetre
ppm	Parts Per Million
rpm	Revolutions Per Minute
pH	Potential of Hydrogen
km^2	Kilometres Square
m^2	Metres Square
g	Gram
mg	Milligram
μg	Micron-gram
ml	Millilitre
XPL	Cross-polarized
PPL	Plane Polarized
BDL	Below Detection Limit

LIST OF SYMBOLS

°	Degree
’	Minute
”	Second
℃	Temperature (degree Celcius)
%	Percentage
?	Still unknown or ambiguous
>	Greater than
<	Less than
x or X	Times (magnification of)
>>	Input or the next step (Computation)
σ_1	Sigma 1 (maximum principal stress)
σ_3	Sigma 3 (minimum principal stress)
e^{-n}	10 to the power of negative or 10^{-n}
n	Number
-	No data

FYP FSB

CHAPTER 1

INTRODUCTION

1.1 General Background

Metal has always been an important resource for the advancement of technology and industrial development since the late Neolithic age but the source of metal---ore would rarely perfectly appear on surface where can be easily extracted to produce the material that human need. Thus, mineral exploration has been applied to prospect the mineral reserves or locations of the ore bodies which are economically mineable and extractable with physical and chemical means.

Many environmental researches show that heavy metals are not favourable to many flora and fauna. Thus ideally, plants that thrive in the heavy metal region must have good adaptation and strong tolerance towards heavy metal which might make occurrence of these plants a very good indicator of heavy metals through chemical analysis or even through observation on their raw morphologies. However, in reality, many plants have the ability to withstand certain amount of heavy metals. Thus instead of sole observation at only one plant species, the assemblage of plants living in heavy metal bearing area should be studied in order to find a plant or a group of plants which may able to indicate the presence of gold.

To utilise these characteristics of flora, a better understanding can be gained by biogeochemistry which studies the complex interaction between geological components where the metals originates and the plants from biosphere. Geobotanical approach in metal searching is the identification of the occurrence of near-surface or subsurface metal through a living of a certain plant or certain physiological behaviour of a plant.

Sokor of Kelantan state is famous with its largest gold reservoir in Malaysia as located in the Central Gold Belt of Peninsular Malaysia which is thus very suitable for heavy metals especially gold-related researches as in many studies those have been done in this area (Li, 2014; Hadi, 2013; Syazwani, 2013; Sofian, 2017). In order to elucidate and have a deeper understanding towards the biogeochemistry of Sokor, geology of the Sokor should be well-understood to make connection between the geology and the living things which is specified in this study--- plant through the chemical pathway. Thus a geological mapping and study of plants, soils and rocks had been carried out to draw the relationship between these entities.

1.2 Study Area

Sokor, a reserve forest with the largest gold reservoir in Malaysia with epithermal gold deposit, hosted in Permian-Triassic volcanic rocks where gold has been placer mined for about 100 years from Rixen, New Discovery and Manson lodes (deposition beds). Based on the satellite image, it is noticeable that the study area is 90% covered by the thick Sokor Taku Forest Reserve. Coordinates of four corners of the 25 km^2 box in clockwise are 101° 59' 36.712''E 05° 36' 36.9333''N, 102° 2' 23.655''E 05° 36' 36.152''N, 102° 2' 23.983''E 05° 33' 48.354''N and 101° 59' 36.499''E 05° 33' 14.76''N. Base map of study area is shown in **Figure 1.1**.

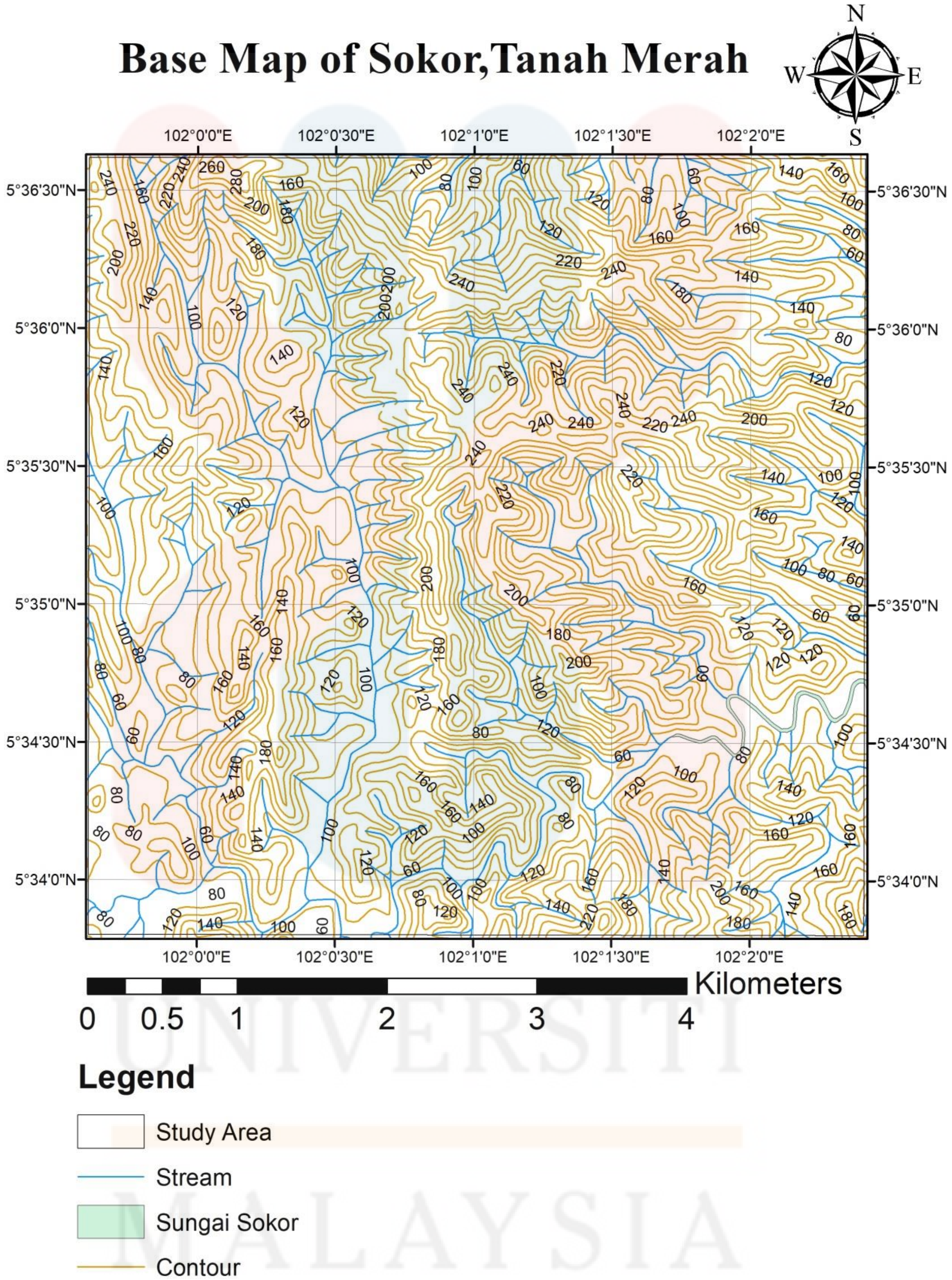


Figure 1.1: Base Map of the Study Area. No road is shown as the whole study area is of off-road.

1.2.1 Location

The study area is under Tanah Merah District. As the name indicates, Tanah Merah was part of the earliest civilization of South-East Asia with the name of *Chih Tu* (Red Earth) in the 7^{th} century. Before 1952, Tanah Merah was under the district of Pasir Mas, not until 1952, Tanah Merah District Council was first established with total area of 1.95 kilometres square then upgraded as Tanah Merah Municipal Council in 1958 with total area of 10.4 kilometres square.

In January 1979, Tanah Merah Municipal Council was then combined with 7.8 kilometres squared Gual Ipoh and 2.6 kilometres squared Kusial Baru Local Councils which were previously established in 1962 and also Batang Merabu, Batu Gajah, Bukit Bunga, Bukit Panau and Kuala Tiga with the enforcement of Local Government's Act 1976 (Act 171) due to administration restructuration for mutual economic growth under supervision of a Local Superintendent thus the total area of Tanah Merah Municipal Council was 136.60 kilometres square in 1979.

On 1^{st} September 2005, the council administrative area was again upgraded to 867.67 kilometres square with population of 103,487 people. The council population is majorly made up by Malay 95%, Chinese 3% and Indian 1%. **Figure 1.2** shows the location of Tanah Merah District.

Relativly, Tanah Merah Municipal Council is surrounded by Pasir Mas at the north, Ketereh in the northeast, Machang at the east, Kuala Krai at the south East, Jeli at the south and southwest and Sungai Kolok, Thailand at the northwest. Tanah Merah is reachable by the east side of Peninsular Malaysia railway , and the roads connected from Jeli, Pasir Mas, Machang and Jedok.

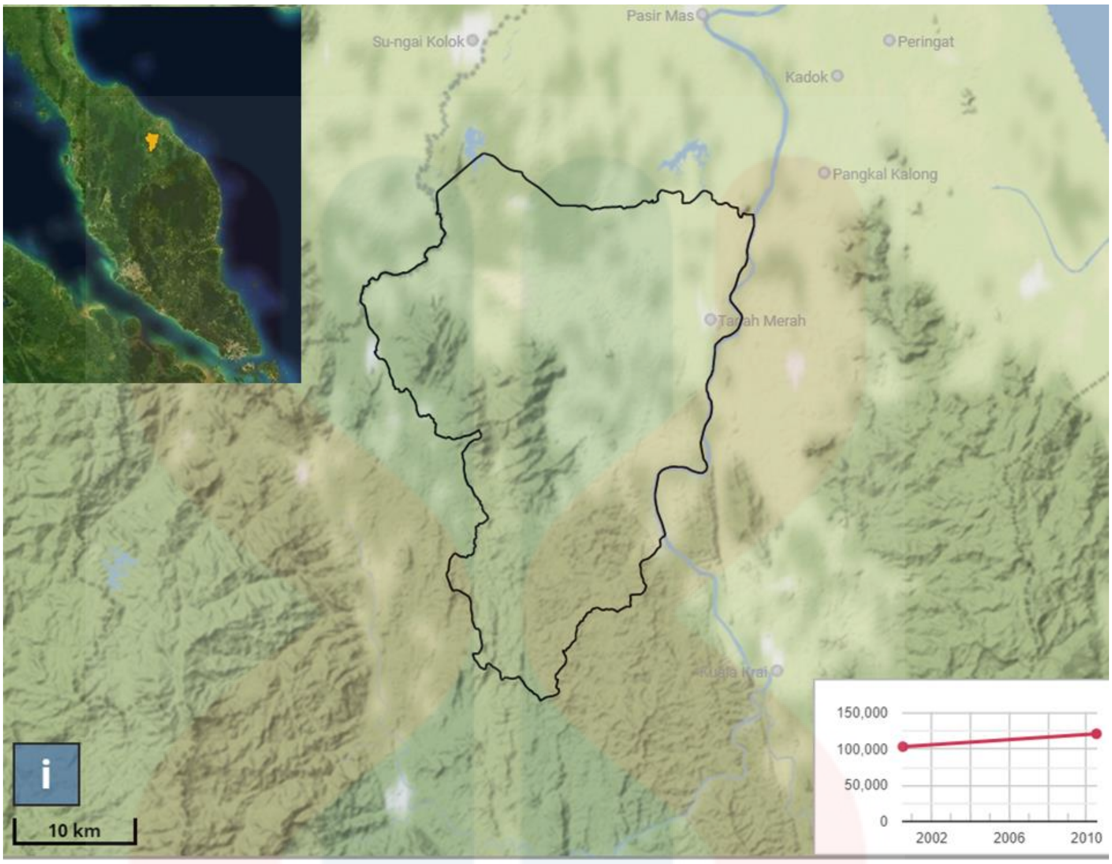


Figure 1.2 shows the terrain map of Tanah Merah District bounded by balck line and the location of Tanah Merah District in Peninsular Malaysia (the upper left corner) in yellow shade. Image was retrieved from https://www.citypopulation.de/php/malaysia-admin.php?mode=status&adm2id=0306 on 5th December, 2018.

1.2.2 Road connection/ Accessibility

Since there is no paved road to enter the study area as shown in the base map in **Figure 1.1**, it is expected that the visitors are equipped with a 4 x 4 wheels vehicle as the study area is in an off-road condition. There is also no auto-generated calculable trip from the higher learning institute of Universiti Malaysia Kelantan of Jeli Campus to the study area, as shown in **Figure 1.3**.

However, also according to the previous studies near this area, the study area can be entered within two to three hours by traveling through the main road of Jeli-

Grik or East-West Highway to Gual Ipoh by turning right into Jalan Ipoh and turning to the right T-junction at Pekan Kusial. The study area can be entred through the unpaved roads of entering Sokor Taku Logging Area.

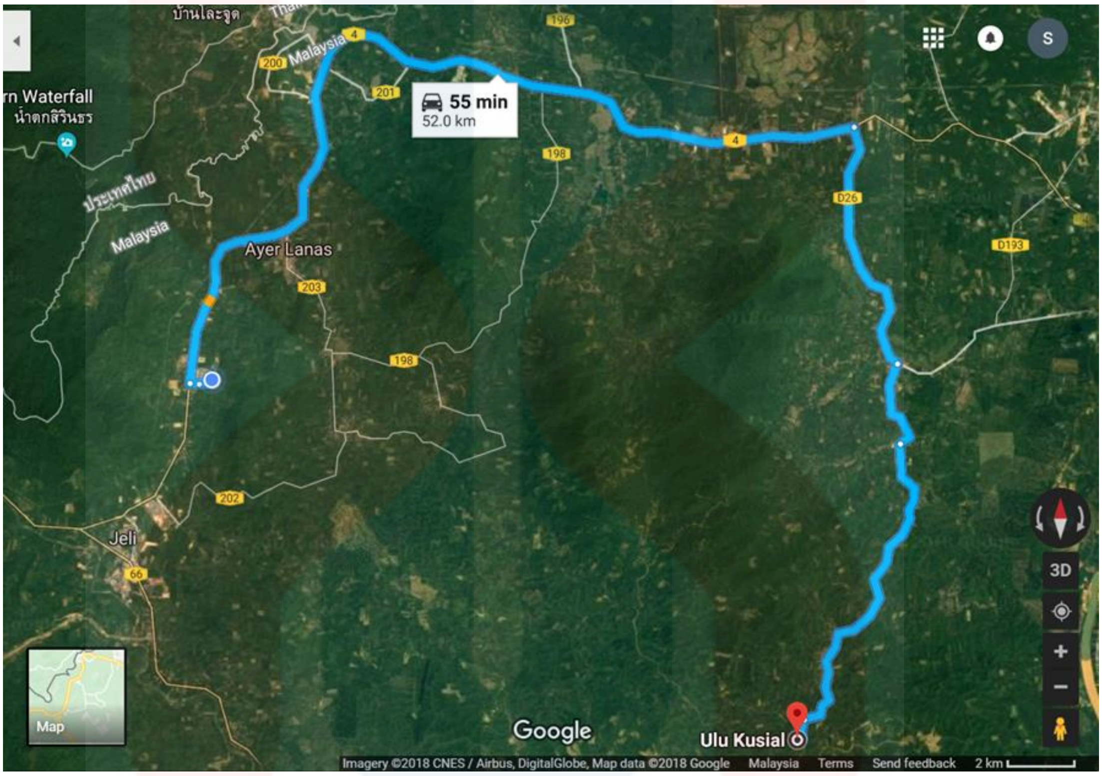


Figure 1.3 shows the Google satellite images retrieved from Google Map on 4th December, 2018. The bright blue circle is Universiti Malaysia Kelantan of Jeli Campus while the red pin is one of the corners of the study area with coordinate 101° 59' 36.712"E 05° 36' 36.9333"N. It clearly shows that there is no public road to transport to this study area.

1.2.3 Demography

Since there is no record of particular demography of the study area, the demography of the whole Kelantan or some specific data of Tanah Merah District is tabulated in this section. Total number of residents in Kelantan according to a survey conducted in 2016 was 1.80 million and the breakdown according to period is as shown in **Table 1.1**.

According to the Economic Planning Unit of the Kelantan State in 2010, the average population density of the Tanah Merah District was 135 people/km^2 with a yearly growth rate of 1.41%. But in 2017, the average annual population growth rate was 1.8% by the DOSM and the sex ratio was quite balanced where 92 males to 97 females. The ten year- interval demography of Tanah Merah is shown in **Table 1.2**.

Table 1.1: Kelantan Demography

Year	2013	2014	2015	2016	2017
Estimated Population (million)	1.68	1.72	1.76	1.80	1.83
Recorded Population	1,683,500	1,723,400	1,760,600	1,810,400	1,829,900

Source: Department of Statistic Malaysia (Official Portal)

Table 1.2: Tanah Merah Demography in ten years interval

Year	Census 2000-07-05	Census 2010-07-06
Population	101,509	116,880

Source: Department of Statistic Malaysia (Official Portal)

1.2.4 Landuse

The 15,101 kilometres square or 1,302,200 hectares of Kelantan has 45% state land, 33% of reserve land and 21% lands for others function. In districts of part of Tanah Merah, Jeli, Kuala Krai and Gua Musang in southern Kelantan, forests cover 60% of the land. According to the Economic Unit of Kelantan State Government, 22% of land in Kelantan especially in rural area is used for agricultural activities. Mining land, which part of it is the concern in this study as in identifying the potential plant species, has coverage of 0.3% as shown in **Table 1.3**.

Table 1.3: Landuse of Kelantan

Category	Area (hectares)	Percentage (%)
Forest Reserve	894,271	59.5
Agriculture	335,660	22.3
Urban	4,967	0.3
Mining	3,737	0.3
Others	263,565	17.6
Total	1,302,200	100

Source: Economic Unit of Kelantan State (Official Portal)

Near to the gold mining sites and logging area, the study area is thickly covered by the forest and bushes. There is some unpaved road in the study area indicating there are some coming logging, agricultural or mining activities in this region. The dense natural vegetation in the area is because of the rain tropical climate of Malaysia and also flourished by the Sokor River. The study area is thus considered as an isolated rural area. Information in **Table 1.3** also tells that the state is still developing and many of the natural resources are being exploited. The occurrence of any economically feasible minerals or other natural resources reserve may bring rapid development to a particular area.

1.2.5 Social Economic

Kelantan is an Islamic state which prohibit movie entertainment, alcoholic and gambling economic activities. With the rich natural resources hidden from previous exploitation by the mountainous and hilly landscape, economic activities in Kelantan are greatly connected and dependable to the nature.

Table 1.4 summarizes the socioeconomic of Kelantan from 2013 to 2016 showing the overall improvement of Kelantan socioeconomic. It shows the high participation labour force in developing the socioeconomic of Kelantan. Advance in technology has replaced the man power with machines that are more economically feasible to the manufacturers and also farmers. However it has increased the unemployment rate in the state. Thus it has become the government responsibility in providing the platform to connect to the data world of internet that must also be connected with the own initiative of citizens to utilise the technology to generate entrepreneurial and employment opportunities for own and more people.

Table 1.4 summarizes the socioeconomic of Kelantan from 2013 to 2016.

Year	2013	2014	2015	2016
Total Gross Domestic Product Growth (%)	3.3	5.1	3.5	4.8
Unemployment Rate (%)	2.8	3.3	3.6	3.8
Labour Force Participation Rates (%)	59.3	60.3	61.9	59.1

Source: 2013 - 2017: Population Estimates based on the adjusted Population and Housing Census of Malaysia 2010. Department of Statistics Malaysia (Official Portal).

The Gross Domestic Product (GDP) in accordance of sectors in Kelantan 2010 shows that the state is being developed rapidly with the exploitation of natural resources as shown in **Table 1.5** with a total GDP rate of 5.0%.

Table 1.5 shows Gross Domestic Product (GDP) of Kelantan in 2010.

Sector	Growth (%) based on constant price of 2010
Construction	29.6
Mining and Quarrying	12.1
Agriculture	2.9
Light Manufacturing Industry	2.1
Total GDP Growth (%)	5.0

Source: Department of Statistics Malaysia (Official Portal)

Construction development indicates there are more areas of Kelantan is no longer covered by forests and have been developed as residential settlement and other economic purposes. Mining and quarrying sector is also developing with the discovery of new mine lodes of precious metals such as gold. Commercial plantation of oil palm, rubber, tobacco, paddy, vegetables and fruits which are part of the traditional economic activities of this state is also developing in also developing together with upstream and downstream of light manufacturing industry of wood, food, textile, electrical and non-metallic products.

The study area is near to the plantation, logging and mining areas which most probably the villagers nearby are involving in this economic activities and also small business for providing daily items for the workers. With no doubt, the forest rangers, geologists, geographers and surveyors are parts of temporary residents of this study area during their inspections and investigations in this area. The town area in Gual Ipoh is the nearest town to the study area, provides basic functional services such as health care, social security and business activities through rural clinics, police station and small shops.

1.3 Problem Statement

Biogeochemistry is a very exciting field but it requires multidisciplinary knowledge in order to understand a biogeochemical process especially its application in mineral prospecting. The studies of biogeochemical of metals are currently considered limited as the geobotanical researches of metals are mostly based on plants in the temperate region which especially have been a great effort by Colin E. Dunn from late 1980s until his writing of “Biogeochemistry in Mineral Exploration” in year 2007. The metal or mineral prospecting plant and its biogeochemistry is less studied in the humid tropical region like Malaysia (Bakers & Brooks, 1988). The geology of the study area should also be updated from time to time to provide more details for current and coming studies.

1.4 Objective

The objectives of this research are:

1. To produce an updated geological map of Sokor, Tanah Merah, Kelantan at scale of 1: 25 000
2. To determine element concentration in plant and soil using geochemical analysis
3. To study relationship between geochemistry and mineralogy with plant using plant and soil in Ulu Sokor

1.5 Scope of Study

5 x 5km area in Sokor was selected for this study as well as for geological mapping. The geology of Sokor, Tanah Merah, Kelantan was always referred to the previous geological studies and researches and through geological mapping with focuses in structural geology, stratigraphy if applicable and petrography. This had involved desk study, field work observation and rock sample collection and identification and also petrographic lab studies. In order to visualize metal elements distribution, geochemical anomaly maps were produced.

This biogeochemical study is focused in the metal elements concentration in the plant species and its morphology. The elements or compounds concentration of plant and soil beneath it were analysed through FTIR, AAS, ICP-MS, XRD and XRF which has reflected the interaction of chemical elements between biosphere and lithosphere or in this case pedosphere. A high metal concentration would indicate the high adaptation of the plant or high absorption rate of metal by the plant, thus a total distinct plant species or the plant species with obvious morphological difference would be a good indicator of certain metal.

1.6 Significance of Study

Understanding towards the study area is vitally important for a biogeochemistry as it is a cycle between interactions of the Earth spheres. An updated map through geological mapping is able to confirm or update the geological changes in the study area if applicable. A biogeochemical study of a certain plant species might make it a very good indicator of certain metal in certain region, thus contributes to metal or mineral prospecting through botanical approach by knowing the occurrence of certain plant species or observing the significant differences between plants thrived in the soil with different amount of metal elements. The method can greatly reduce the time and cost to blindly search for metal as done before by some residents who do not have a mineral prospecting background. This research has hopefully provided a better understanding towards the interaction of biosphere--plant with the metal elements of the lithosphere thus advancing the complex biogeochemical field.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter describe the whole picture of geology in the study area found by the previous studies in term of regional, tectonic setting, stratigraphy, structural and historical. It has also included some brief history and trends of biogeochemistry and the similar and related studies that have been done.

2.2 Regional Geology and Tectonic Setting

The latest detailed compile work of Kelantan state geology was done by C.S Hutchison and D.N.K Tan in Geology of Peninsular of Malaysia 2009 shows that Kelantan can be chronologically divided into Palaeozoic, Mesozoic and Cenozoic by sedimentary and metasedimentary rocks and is also made up of extrusive rocks and Main Range and Boundary Range granitic rocks (Department of Minerals and Geoscience, 2003). In term of structural geology of the Kelantan state, North-south to northwest-southeast (NS-NWSE) directions are the main structural pattern of Kelantan. The general geology and structural geology of Kelantan are clearly shown in **Figure 2.1**. Geomorphogically, mountainous, hilly, plain and coastal areas are the four types of landscape in Kelantan (Unjah et al 2001) with all previous three landscapes exist in the study area excluding the coastal landform.

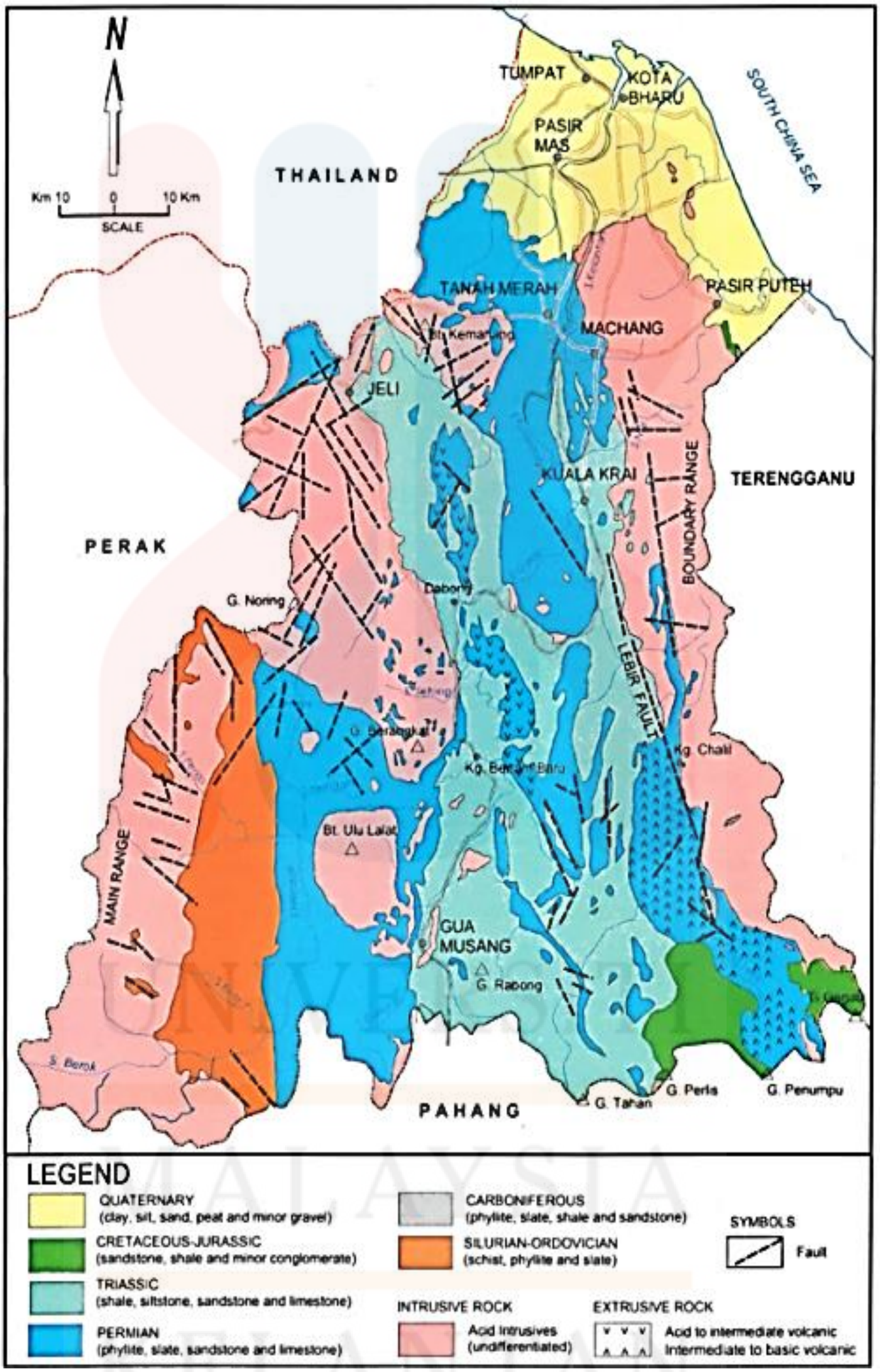


Figure 2.1: Geological Map of Kelantan

Source: Department of Mineral and Geoscience (2003)

The tectonic setting of South East Asian including Malaysia and the state of Kelantan is greatly discussed by the late Professor Emeritus Charles Starchan Hutchison of University Malaya, in his textbook of The Geological Evolution of South-East Asia published by Geological Society of Malaysia in 2007. The following is the summary of his studies and interpretation:

Peninsular Malaysia is divided by the prominent N–S Palaeo-Tethys Bentong-Raub suture divides into a Sibumasu block on the west and an Indochina block on the east, locally known as East Malaya; or geographically named as West Coast and East Coast of Peninsular Malaysia.

The suture zone is characterized by an imbricated complex resembling an accretionary prism, of carbonaceous pelitic schist, serpentinite, amphibole schist, mélange-olistostrome and chert, as well as undated post-suture redbeds. Oceanic cherts record a Palaeo-Tethys history from Late Devonian to at least Late Permian.

Extrapolation southwards is towards the Indonesian islands of Bangka and Billiton, and northwards along the Gulf of Thailand to the Sa Kaeo suture that has been strongly offset left-laterally by the Chao Phraya and Mae Ping faults to the Nan Uttaradit Suture, associated with less prominent island arcs of the Sukhothai zone, that correlates with the western part of East Malaya. Sa Kaeo and Nan-Uttaradit are now interpreted as closed back-arc basins. The suture zone accretionary prism and associated island arc rocks are known in northern Thailand as the Inthanon zone associated with the Chiang Mai suture, equivalent to the Bentong-Raub suture zone of Peninsular Malaysia, but problems of polarity remain, shown in **Figure 2.2**.

Sibumasu is characterized by Carboniferous–Permian glacial pebbly mudstones, whereas the East Malaya and Indochina Block are characterized by fusulinid limestones and Cathaysian equatorial *Gigantopteris* flora. Sumatra has a Cathaysian affinity terrain west of the Sibumasu Block, formerly referred to as the "Jambi Nappe". Characteristic Lower Palaeozoic fossils allow the Sibumasu localities of Langkawi, Tarutau and Phuket to have been positioned near the Canning Basin of Australia before its Lower Permian rifting from Gondwanaland. The Indochina and South China terranes had rifted from Gondwanaland in the Early Devonian and were spared the Upper Palaeozoic glaciation and instead developed equatorial *Gigantopteris* flora.

Sibumasu collided with East Malaya and Indochina in the Late Triassic (the Indosinian Orogeny), shown in **Figure 2.3**, causing crustal thickening resulting in important tin-bearing S-type granites, characterised by the Main Range of the Peninsula, the 'tin islands' of Indonesia and parts of central Thailand. However, the Late Cretaceous granites, commonly associated with high grade metamorphic core complexes, have not yet been successfully integrated into the regional tectonic analyses.

2.3 Stratigraphy

Sokor consists of three formation, from youngest to oldest, are Kemahang granite, Taku schist and Gua Musang formation (Department of Minerals and Geoscience 2003). In Sokor area, Kemahang granite formation is an Triassic aged porphyritic granite intrusion into the Permian to Triassic mica-schist of Taku schist formation and middle Permian to Upper Triassic Gua Musang formation, Telong or Sokor Formation which are mostly interbedding siltstone, feldspathic litharenite sandstone and shale (Hadi, 2013; Syazwani, 2013; Sofian, 2017).

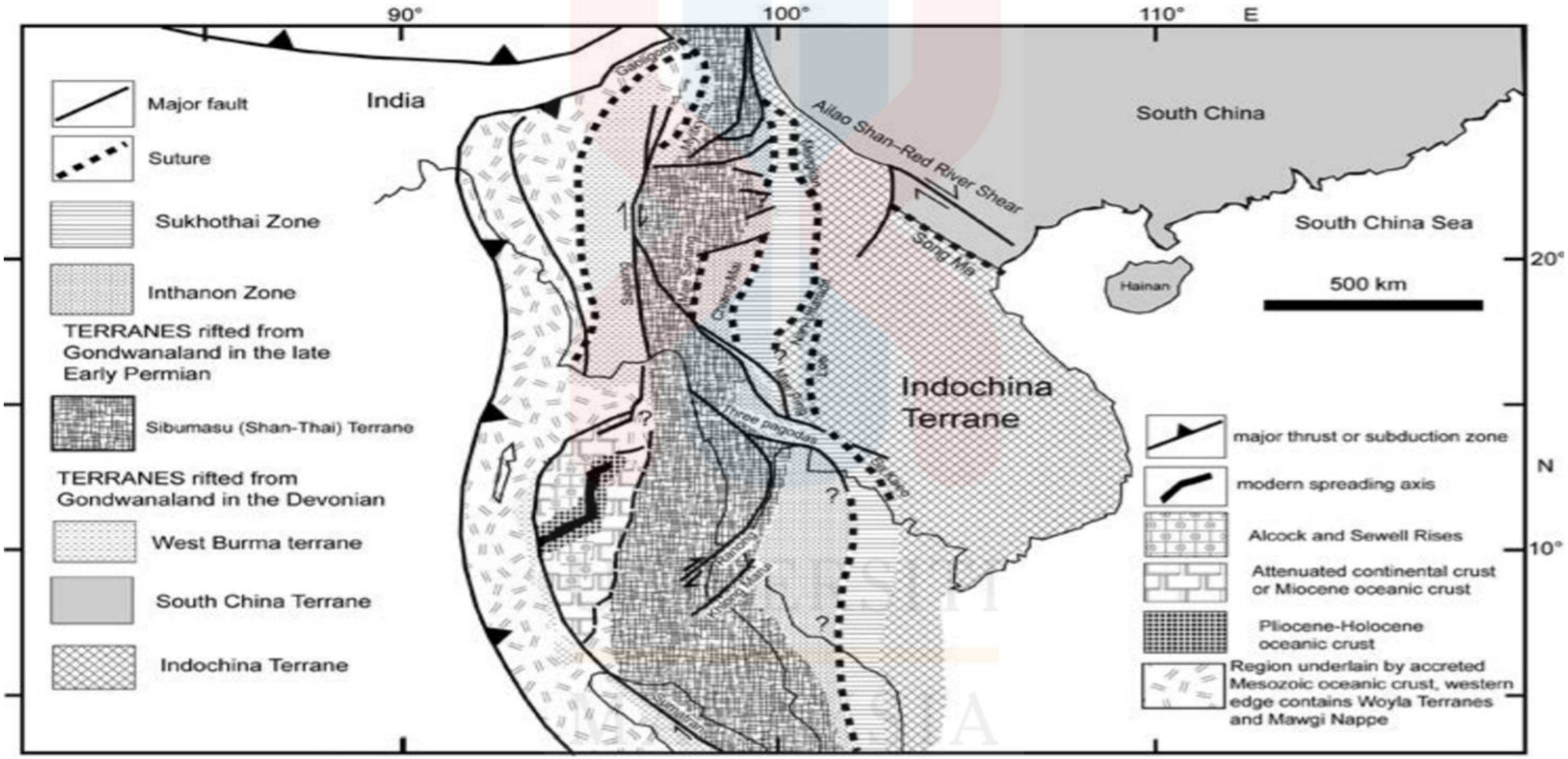


Figure 2.2: Geological terrane map of northern Southeast Asia showing the sutures and major faults, modified from Searle and Morley (2011). The Palaeo-Tethys and island arc terrane is that proposed by Sone and Metcalfe (2008a). The Sukhothai Zone is one of island arcs on the western margin of the Indochina block. The Inthanon Zone includes a record of the Palaeo-Tethys Ocean, mainly accretionary prism. Source: Hutchison, 2014

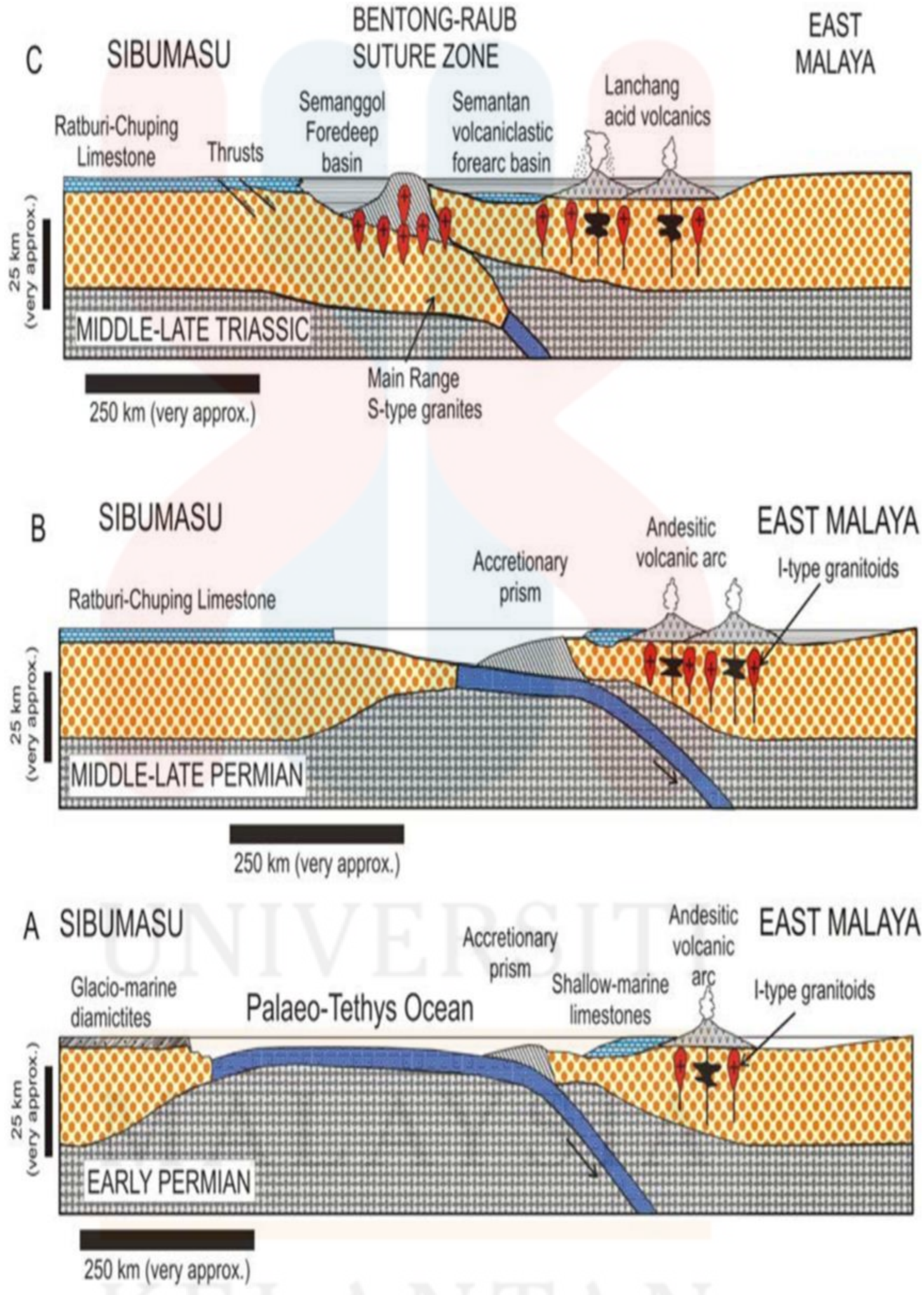


Figure 2.3 shows the conceptual cross-sections illustrating formation of the Bentong– Raub Suture by subduction of the Palaeo-Tethys Ocean and collision of Sibumasu with the East Malaya (Indochina) terrane during the Indosinian Orogeny. Modified after Metcalfe (2000).

The basic stratigraphy information of Gua Musang, Telong (Sokor) and Taku Schist Formations are summarized in **Table 2.1**.

2.3.1 Gua Musang Formation

Gua Musang Formation, a formation of argillaceous and calcareous rocks interbedded with volcanic and arenaceous rocks, was formed 270.6 million to 199.6 million years ago which is the Middle Permian to Upper Triassic epochs. The name is after Gua Musang town in south Kelantan. Various researches have been done towards the formation including Yin (1965), Burton (1973), Khoo(1983), Fontaine et al. (1986), Fontaine et al. (1994), Metcalfe (1992), Igo et al. (1965), Mohd Shafeea Leman (1993), Kobayashi & Tamura (1968). The type area of Gua Musang Formation is Gua Musang area of south Kelantan, exyended to north Kelantan and north Pahang.

The lower boundary of Gua Musang is unknown whereas the upper part is overlain by the Koh Formation but the nature of upper boundary is also unknown. The upper part of Gua Musang Formation is interfingering with the Semantan Formation, ?Telong Formation and Gunung Rabong Formation.

There are abundant fossils in Gua Musang Formation, ranging from the phylum of algae, bivalve, brachiopod, cephalopod, conodont, coral to foraminifera. This fossil assemblage indicates a shallow marine shelf deposit of active volcanic activity together with the argillaceous and calcareous rocks interbedded with volcanic and arenaceous rocks formed during 270.6 million to 199.6 million years ago.

2.3.2 Telong Formation

Telong Formation also called Sokor Formation made up of sequence of predominantly argillite associated with some tuff is most probably formed during Permian to Upper Triassic (Carnian) which is 298.8 million to 227 million years ago. But there is a debate about the age of this formation. Khoo (1983) mentioned that the age of Telong formation is probably of Middle to Upper Triassic, while Aw (1990) suggested a ?Permian to Upper Triassic age for this formation.

The name of Telong Formation is after a tributary of Sungai Aring named Sungai Telong in south Kelantan. This formation can be referred to Aw (1999) and Khoo (1983). The type area is in Sungai Telong, the upper reaches of Sungai Aring in south Kelantan while the type section is along upstream of Sungai Telong.

Telong Formation is unconformably overlying the Gua Musang Formation and unconformably overlain by the Koh Formation. Telong Formation is also most probably lateral equivalent to Gunung Rabung Formation and Sematan Formation. The thickness of the Telong Formation is more than 1000 metres.

There are some fossils found in this formation from phylum of bivalve, and cephalopod. Bivalve fossils are represented by *Amonotis* sp., *Costatoria pahangensis* Kobayashi & Tamura, *Costatoria quinquicostata* Kobayashi & Tamura, *Costatoria* sp., *Entolium* sp., *?Hoernessi*a sp., *Langsonella* sp., *Lima* sp., and *Neoschizodus* sp.. Cephalopod are shown by the occurrence of *Anatomites* sp. and *Hoplotropites* sp.. This fossils assemblage indicates a stable shallow marine environment with occasional supply of fine pyroclastic material.

2.3.3 Taku Schists Formation

Taku Schists, is literally like its name, are mainly made up of mica garnet schists and quartzmica-garnet schists with narrower bands of quartz schists and serpentinite with rare talc-carbonate schsits. This formation has once been referred to Kelantan schists by Savage (1925). Although Khoo & Lim (1983) put the age as PermoTriassic which is 298.8 million to 201.3 million years ago, Khoo (pers comm 1997 in Lee et al, 2004) suggested that the core of the Taku Schists is most probably Pre-Permian while the Permo-Triassic rocks at the edge are equivalent to the Gua Musang formation due to the presence of limestone bodies. Thus, this formation can be correlated to the eastern foothills of the Main Range.

Taku Schists Formation got its name from the Sungai Taku in central East of Kelantan. It is also true that the type area of Taku Schists Formation is Sungai Taku and its tributaries, near Manik Urai, central east Kelantan.

2.4 Structural Geology

The localized structure included fold and joint in sedimentary rock while the joint and fracture occurred in the granitic rocks (Hutchison & Tan, 2009). Based on the geological map of Departmemt of Mineral and Geoscience Malaysia, also shown in **Figure 2.1**, the fault in the study area may be reverse, oblique slip, normal, conjugate strike-slip associated with the surface of slickenside.

Two major geological structure have been observed in Ulu Sokor which are fold and fault (Hadi, 2013; Syazwani, 2013; Sofian, 2017). Fold and fault of Permian meta-sedimentary rocks of Gua Musang and Telong Formations was most probably caused by the regional compression and normal fault that formed in the central belt of Peninsular Malaysia (Li *et al.*, 2011) whereas the fault in Pre-Permian meta-sedimentary rocks of Taku Schist Formation act as an indicator of compression tectonics of Late Triassic by the granitic intrusion (Li *et al.*, 2011).

2.5 Historical Geology

Ulu Sokor before Permian is in shallow marine shelf with occasional volcanic eruption. It was then uplifted by the Indosinian Oregeny when the active continental margin of Sibumasu Plate collided with the volcanic Island arc of Indochina Plate during Late Triassic. The history has been shown in **Figure 2.2** and **2.3** under section 2.2 Regional Geology and Tectonic Setting. The later granitic intrusion has enabled the enrichment of hydrothermal fluid for the gold ore lodes formation (Chen, 2014; Chen, 2013).

Age	No	Name	Type Area/ Type Section	Boundaries	Correlation	Lithology/ Thickness	Fossils	Depositional Environment
Middle Permian to Upper Triassic	1	**Gua Musang Formation** After Gua Musang town in south Kelantan Ref: Yin (1965), Burton (1973), Khoo(1983), Fontaine et al. (1986), Fontaine et al. (1994), Metcalfe (1992), Igo et al. (1965), Mohd Shafeea Leman (1993), Kobayashi & Tamura (1968).	Gua Musang area, south Kelantan (extended to north Kelantan and north Pahang)	Lower boundary is not known; Upper boundary is overlain by the Koh Formation (nature of boundary is not known)	The upper part of Gua Musang Formation is interfingering with the Semantan,Telong and Gunung Rabong Formation	Argillaceous and calcareous rocks interbedded with volcanic and arenaceous rocks	Algae Bivalve Brachiopod Conodont Coral Foraminifera	Shallow marine shelf deposit, with active volcanic activity

?Permian to Upper Triassic	2	**Telong Formation** After Sungai Telong (a tributary of Sungai Aring) in south Kelantan Ref.: Aw (1990), Khoo (1983)	Sungai Telong, the upper reaches of Sungai Aring in south Kelantan/ Along upstream of Sungai Telong	Unconformably overlying the Gua Musang Formation and unconformably overlain by the Koh Formation	?Lateral equivalent to Gunung Rabung Formation and Semantan Formation	Sequence of predominantly argillite associated with some tuff/ More than 1000 metres	Bivalve Cephalopod Listed in the section 2.3.2	Stable shallow marine environment with occasional supply of fine pyroclastic material
Permian to ?Triassic (or older)	3	**Taku Schists** After Sungai Taku, central east Kelantan Ref.: MacDonald (l967), Hutchison (1973) Khoo & Lim (1983) Subdivided into garnet and biotite metamorphic zones in Khoo & Lim (1983)	Sungai Taku and its tributaries, near Manik Urai, central east Kelantan		Schists along the eastern foothills of the Main Range	Mica garnet & quartzmica-garnet schists with narrower bands of quartz schists and serpentinite with rare talccarbonate schsits.		

Table 2.1: Startigraphy of Sokor Area including Gua Musang, Telong and Taku Schists Formation.

2.6 Research Specification

2.6.1 Gold Deposits in Ulu Sokor

Located at the Central Gold Belt of Peninsular Malaysia, Ulu Sokor is one of the major gold-bearing areas (Ariffin, 2015) where many studies have been done. The area was formed by mixing of oceanic crust, andesite and marine volcanic tuff through convergence of a volcanic island arc to an active continental margin which is the collision between Indo-China Plate and Sibumasu Plate where the later intrusion of granitic magma enabled the gold ore formation and enriched by hydrothermal fluid (Chen, 2014; Chen, 2013). **Figure 2.4** shows the major gold bearing area in Peninsular Malaysia while **Figure 2.5** shows the geological gold deposition map in Ulu Sokor and its cross-section.

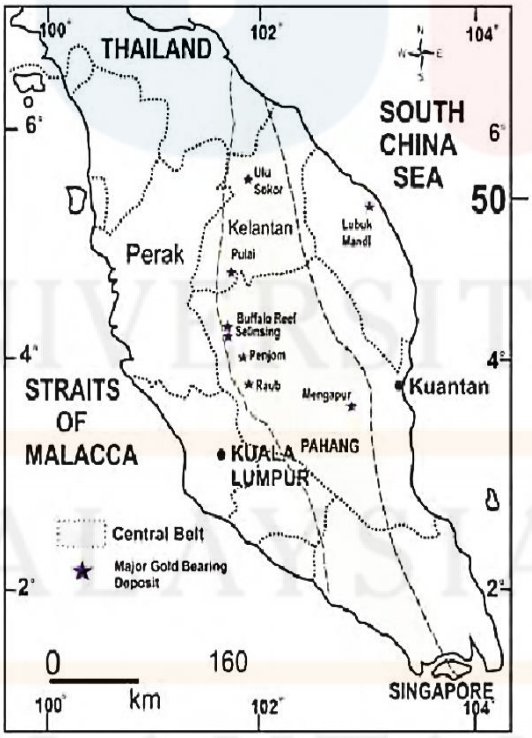


Figure 2.4: Central mineral gold belt of Peninsular Malaysia showing Ulu Sokor, Kelantan is one of the location with major gold bearing deposits
Source: Ariffin, 2012

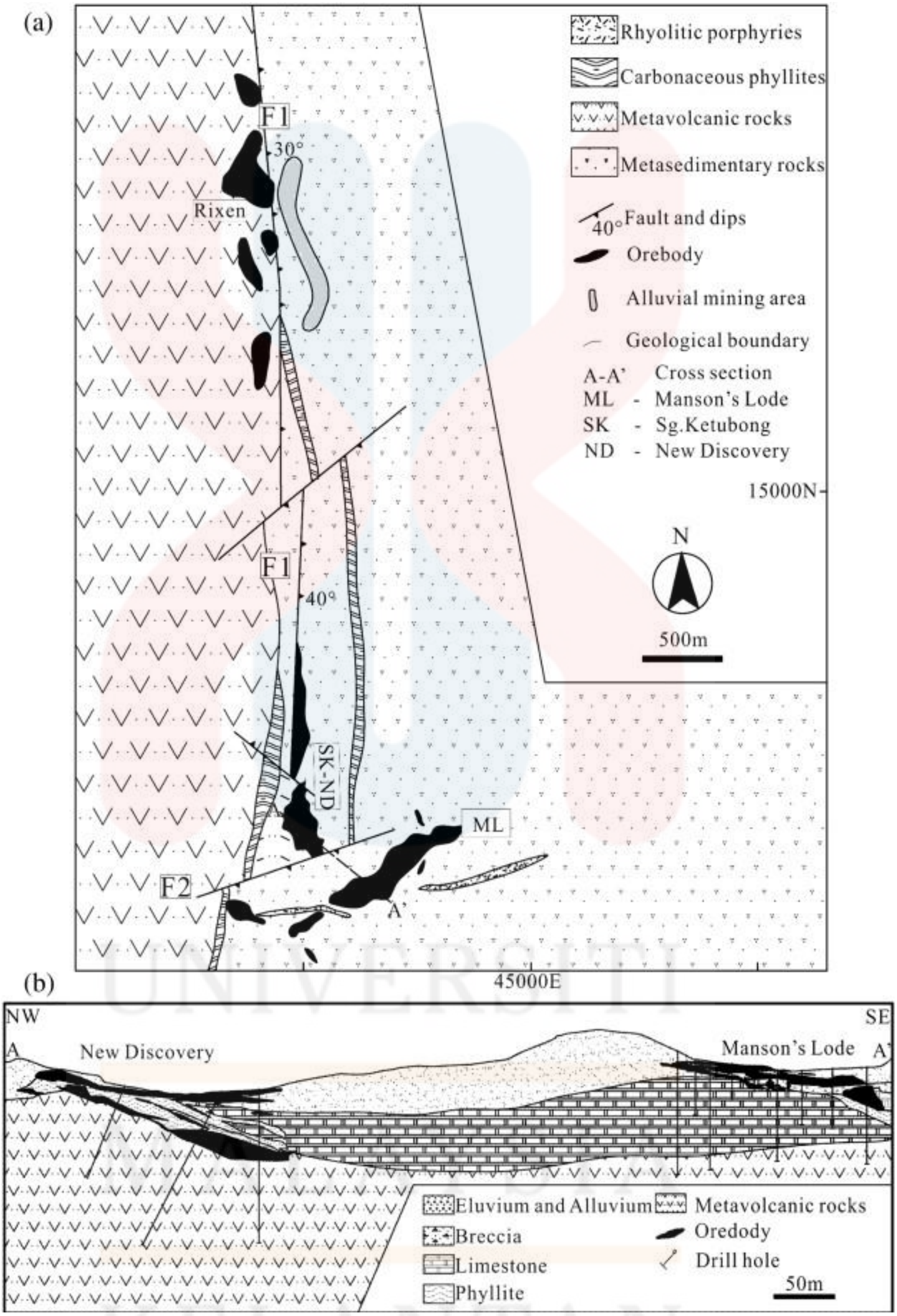


Figure 2.5: a) Generalized geological map of the Ulu Sokor deposit (after Li *et al*., 2010). b) Cross section of the New Discovery and Manson Lode ore bodies (after Li *et al.*, 2010)

Source: Li et al, 2015

2.6.2 Biogeochemistry

The field of biogeochemistry is greatly contributed by the Collin E. Dunn through his researches from year 1986 till 2006 in lake sediments, tills in temperate region until he compiled many of his own work in "Biogeochemistry in Mineral Exploration" 2007. A big success of biogeochemistry is achieved when Christopher W.N. Anderson, Robert R. Brooks, Robert B. Stewart and Robyn Simcock through journal 'Harvesting a crop of gold in plants' in 1998 introduced the concept of metals or specifically gold mining by using plants and greatly enhanced the hyperaccumulation of metals or gold with lixivants where a dry mass concentration more than 100mg/kg (Anderson *et al*, 1998). This style of mining has become a sustainable way of mining comparative to the previous traditional metal mining which is manpower intensive and affecting the environment and landscape adversely.

The studies of biogeochemistry in tropical region after the pioneer study by Lungwitz as earlier as in 1900 are not as prevalent as in temperate region (Baker & Brooks, 1998), especially those related to the precious metal such as gold and the industrial minerals, greatly caused by the huge species richness in tropical region as compared to temperate regions where most biogeochemical researches have started.

Another sub-discipline of biogeochemistry is geomicrobiology which studies the interaction of subsurface microorganism with minerals, example shown in **Figure 2.6**. The recent biotechnology applies microbes for metal extraction such as *Shewanella odenensis* for iron minerals while studies have been carried out currently towards *Delftia acidovorans* and *Cupriavidus metallidurans* which generate solid gold as secondary metabolite (Reith, 2006, 2007; Johnston, 2013).

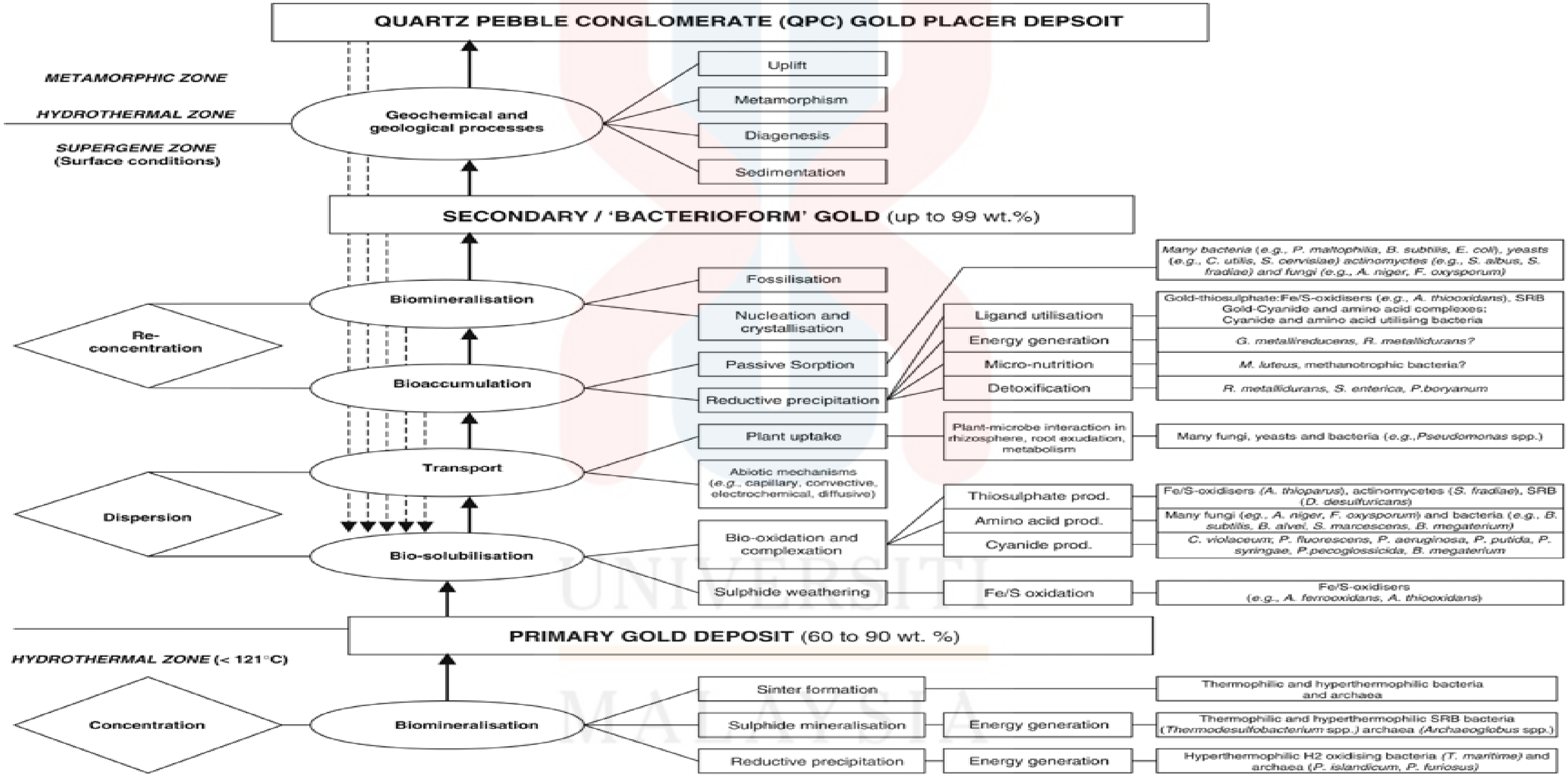


Figure 2.6: Biogeochemical Cycle of Gold.

Source: The Geomicrobiology of Gold (Reith *et al*, 2007)

2.6.3 Metal Prospecting by Using Plants

The early articles regarding metal indicator were always related to field horsetail or *Equisetum arvense* for its ability in indicating gold (Cannon & Shacklette, 1968) which was then rebutted and renamed as an indirect indicator of gold as it also has high arsenic accumulation ability (Brooks, Ryan and Holzbecher, 1981).

Some metal indicators and are shown in the **Table 2.2** and **Table 2.3** which show gold concentration with arsenic and cyanide respectively as in gold mining region in southern British Columbia, Canada (Shewry & Peterson, 1976) and in Wales (Girling & Peterson, 1978). Plants with ability of metal hyperccumulation are shown in **Table 2.4**.

Table 2.2: Old alluvial gold mining region around the headwaters of Stirrup Creek in southern British Columbia, Canada. (after Shewry & Peterson, 1976).

Species	Gold, ppb in dry mass	Arsenic, ppm in dry mass
Cerastium arvense	6.4	18.21
Polemonium pulcherrimum	2.5	2.99
Arctostaphylos uva-uvsi	2.5	4.96
Castilleja miniata	2.3	5.42
Dryas octopetala	1.8	0.70
Lupinus latifolius	1.7	0.26
Pinus contorta	0.7	0.81

Table 2.3: Gold accumulation and Cyanide Content near a Gold mine in Wales (after Girling & Peterson, 1978)

Spesies	Gold, ppb in dry mass	Cyanide, content
Mentha aquatic	49.9	High
Cirsium palustre	26.5	High
Ranunculus aquatilus	8.3	High
Hedera helix	2.9	Low
Ilex aquifolium	2.8	Low
Ulex gallii	1.3	Low

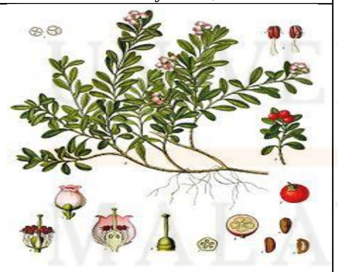
 *Equisetum arvense* Credits: Losch, 1905	 *Populus balsamifera* Credits: Zorn, 1800	 *Pinus radiata* Credits: Antoine, 1840	 *Castilleja miniata* Credits: Lillian Snelling, 1990	 *Dryas octopetala* Credits: Johann G. Sturm, 1796	 *Lupinus latifolius* Credits: Biod. H. Library
 *Artemisia tridentata* Nutt Credits: Peterson, 2001	 *Pseudotsuga menziesii* Credits: BLC, 1999	 Bark of *Pinus contorta* Credits: Zayacskz, 2017	 *Pinus contorta* Credits: NREM	 *Mentha aquatica* Credits: Graham,2016	 *Cirsium palustre* Credits: J. Kops
 *Cerastium arvense* Credits: Koehler, 1887	 *P. pulcherrimum* Credits: Jacob W. Frank, 2014	 *Arctostaphylos uva-uvsi* Credits: Koehler, 1887	 *Ranunculus aquatilus* Credits: Sowerby, 1863	 *Hedera helix* Credits: Thome, 1885	 *Ilex aquifolium* Credits: Thome, 1885

Table 2.4: Plants those have the ability of gold hyperaccumulation.

Finding metal by using plants has never been easy. Generally, in proposing a plant indicator, there are four rules to be followed shared by Nikita through the website of Biology Discussion. First based on the distribution the indicators may be ‘steno’ species or ‘eury’ species. The ‘steno’ is used to indicate narrow limits of tolerance and ‘eury’ is used to indicate wide limits of tolerance. A plant may show wide limits of tolerance for certain conditions and narrow limits of tolerance for other conditions. For example, a plant may be indicator of wide limits of tolerance for heat but of narrow limits of tolerance for water. Plants with wide limits of tolerance of heat are called eurythermal and those with narrow limits of tolerance for water are called stenohydric. Second, plants of large species are better indicator than the plants of small species. Third, before relying on a single species or group of species as indicators, there should be abundant field evidence. Fourth, numerical relationships between species, population and whole communities often provide more reliable indicators than single species.

Many plants can indicate the presence of characteristic metal minerals in the soils. These plants are called metallocoles or metallophytes or in another term mineral hyperaccumulators. Malaysia is under tropical climate, thus the metallophytes of gold are most probably very different from those proposed from the temperate regions.

CHAPTER 3

MATERIALS AND METHODS

3.1 Introduction

This section is to describe the materials and methods that had been used to conduct the research. The research flow chart is shown in **Figure 3.1**.

3.2 Materials

The geological tools and stationaries for field work, apparatus and materials needed in ecological plotting, instrument for gold concentration identification are listed in the following subtopics.

Tools in Geological Mapping

Geological mapping tools used were hammer, base map for traversing, compass, tape global positioning system (GPS), hydrochloric acid (HCl), hand lens, clinometer, field note book, GeoRose, ArcGIS, and CorelDraw. The stationaries used for geomapping were clipboards, A4 paper, pencils, camera/phone, markers, pens, ruler and sample plastic bags for rock samples. **Figure 3.2** shows the tools and stationaries used for geological mapping.

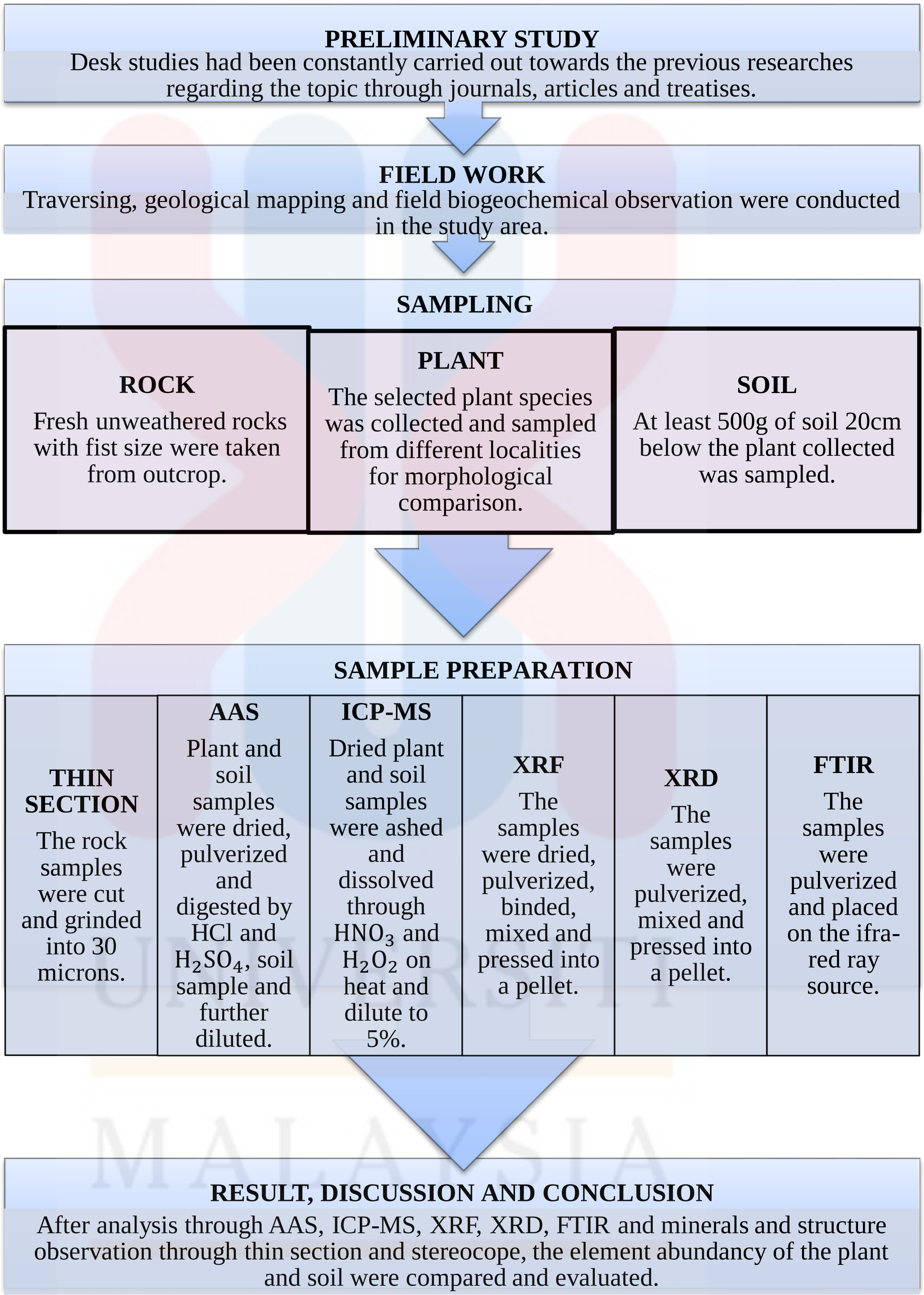


Figure 3.1: Research flow chart of this study.

Figure 3.2: The tools and stationaries used for geological mapping.

Equipment and Apparatus in Chemical Analysis

Chemical analysis of elements in plants, soils and rocks before introducing into the chemical analytic machines: atomic absorption spectrophotometer (AAS), inductively coupled- mass spectrophotometer (ICP-MS), X-ray fluorescence spectrometer (XRF), X-ray diffraction spectrometer (XRD), Fourier-Transform Infra-Red (FTIR) had been pulverized and the certain samples were digested by chemical ranging from nitric acid, HNO_3 , hydrochloric acid HCl, sulphuric acid, H_2SO_4, hydrogen peroxide, H_2O_2 , aqua regia, hydrofluoric acid, HF, perchloric acid, $HClO_4$, lithium metaborate, $LiBO_2$, sodium perborate, $NaBO_3 \cdot {}_nH_2O$. Apparatus for sample digestion are volumetric flasks, beakers, conical flasks, crucibles, Falcon tubes, filter funnel and paper, glass rods, measuring cylinders, syringe and syringe filter, micropipettes and blue tips, and oven. **Figure 3.3** shows tools for sample pulverization, **Figure 3.4** and **Figure 3.5** show materials and apparatus for sample digestion respectively while Figure 3.6 shows equipment for chemical analysis.

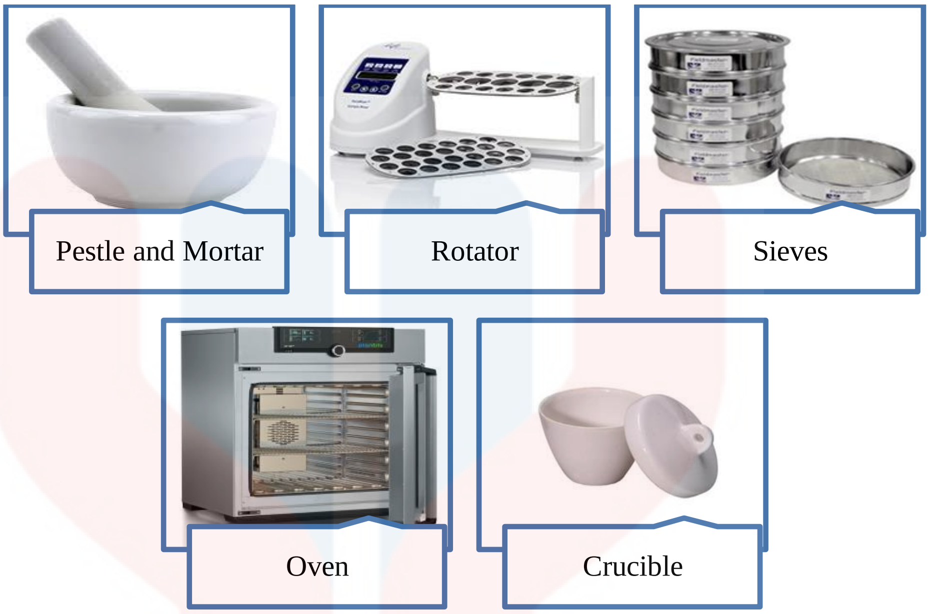


Figure 3.3: Tools for sample pulverization.

Figure 3.4: Materials for sample digestion.

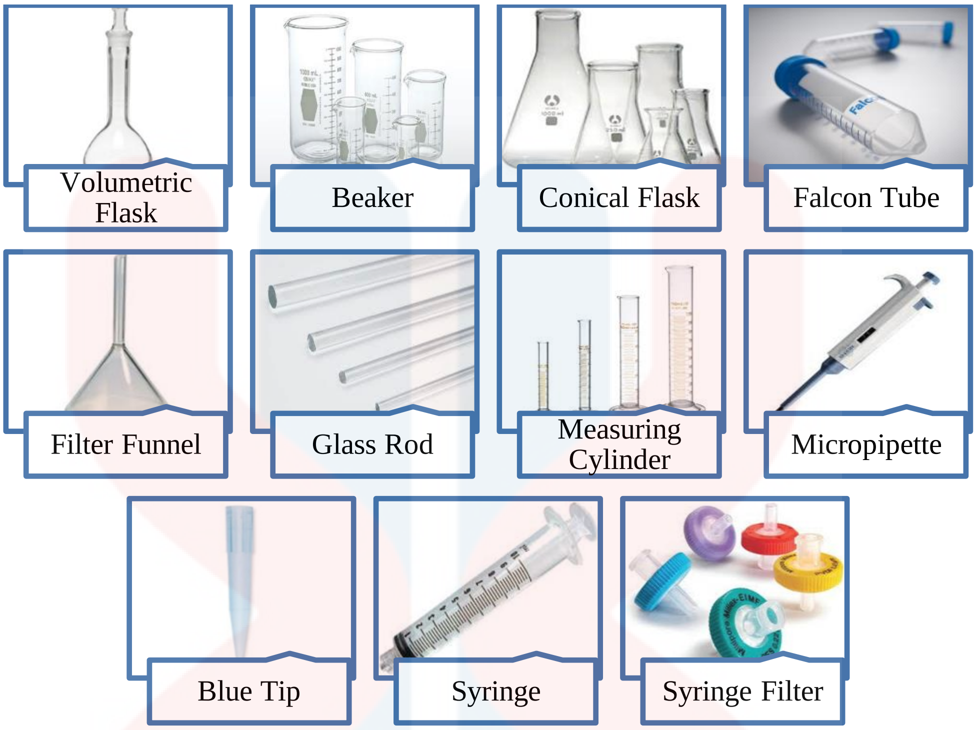


Figure 3.5: Apparatus for sample digestion.

Figure 3.6: Equipment for chemical analysis.

3.3 Methodology

3.3.1 Preliminary Research

Various geological researches or studies have been conducted in area of Ulu Sokor by UMK expertise and undergraduate students, Department of Mineral and Geoscience Malaysia and graduate students from Zhong Nan University of China. The previous researches are mostly studies of gold ore and lodes formation through petrographical analysis, geochemical and geophysical methods. Desk studies through journals were focused on biological, geological and chemical observation and experimental parameters on plants, soils and rocks especially in their metal content.

3.3.2 Field Studies

This project focused on two studies those are geology of Sokor through geological mapping on rock and biogeochemical study of Sokor through soil and plant species observation and sampling.

Geological Mapping

Observation of geology in the field is part of the process of geological mapping. The geological observation was recorded while traversing route in the study area. The data that have been recorded were processed by using GIS software to produce geological map. Strike and dip data, lithology boundaries were taken during mapping. This mapping had involved 5km x 5km area of the study area.

Permission to enter the study area had been asked and granted for geological mapping and the observation of soil and plant.

A GIS database had been created to draft a base map with suitable scale, legends and symbols. Before field mapping, a route had been planned to follow and all the tracks and waypoints during mapping were recorded by Geographic Positioning System (GPS). Pictures of important structures and potential plant species sample collection had been taken and marked for soil and plant observation with jotted notes. Geological and geochemical anomaly maps have also been produced by using GIS with reference to Google Earth.

Soil and Plant Observation

For the biogeochemical study, the study had been focused in the soil and plant. Soil and plant had been observed *in situ* for their morphology especially their colour. Photos have been taken for further comparison. Plant and soil samples had also been collected from the study area for further observation and further processed for characterization.

Sampling

Rock Sampling

Sampling of rock had also been carried out during geological mapping in order to obtain information of lithology that present at the study area with the prior condition where the rock sample should be fresh rock and not weathered and at least fist sized for thin section for petrographic study. The amount of rock samples taken depended on amount of types of rock present at the study area.

Plant Sampling

Old newspapers and sample bags with pores were used to protect the plant structures before reaching to be further processes in laboratory. The roots, stems, leaves, seeds and flowers were well protected. In sampling the plant from different location, the dominant plant at the particular sampling point was chosen.

Soil Sampling

Sample bags and soil sample tubes were used to take the undisturbed soil which is generally 20 cm below the roots of the plants that will be sampled. Auger bore or dig was used when it is necessary for soil mapping. The soil sample was sealed carefully for further laboratory work.

3.3.3 Laboratory Work

Lapidary Work and Petrographic Analysis

The following steps were adapted from the practice of the Mineralogy and Petrology Unit, Technical Services Division of Mineral and Geoscience Department of Malaysia, shown in **Figure 3.7**. First step of making a thin section for rock sample was sample selection where the rock was fresh sample or not too weathered and it must be consolidated if it was a sedimentary rock. Second Step was cutting where the ready-to-cut sample was clamped in a rock cutting machine with a diamond blade with water spray to avoid sparkling. The sample was cut into 3cm x 2cm x 1cm. Thirdly, the surface of the cut sample was then smoothened by grinding on a grinder with carborundum grit 120. Forth, after the smoothened sample was dried on a hotplate, it was then stickled on a glass slide by a fully cooked Canada balsam on a hotplate. It was checked so that there was no air bubble on the adhesion side. Then the glass slide was labelled.

Fifth, after the Canada balsam solidified and the sample was fixed on the glass slide, the sample was thinned by using carborundum of various grit sizes to ensure the thickness of the section 30µm. It was checked under a polarized light by comparison with the birefringence chart. Sixth, the thin section was then covered by a slide with half-cooked Canada balsam and prevented any occurrence of air bubble. Last step was finishing; the unnecessary thin layer of dried Canada balsam was trimmed for the cleanliness and tidiness of the thin section. A standard label was stickled on the finished thin section and the information of the rock; locality, collector and the date collected were recorded. The thin section was then analysed under the plane polarized and cross polarized microscope by identification of minerals in the rock for naming the rock.

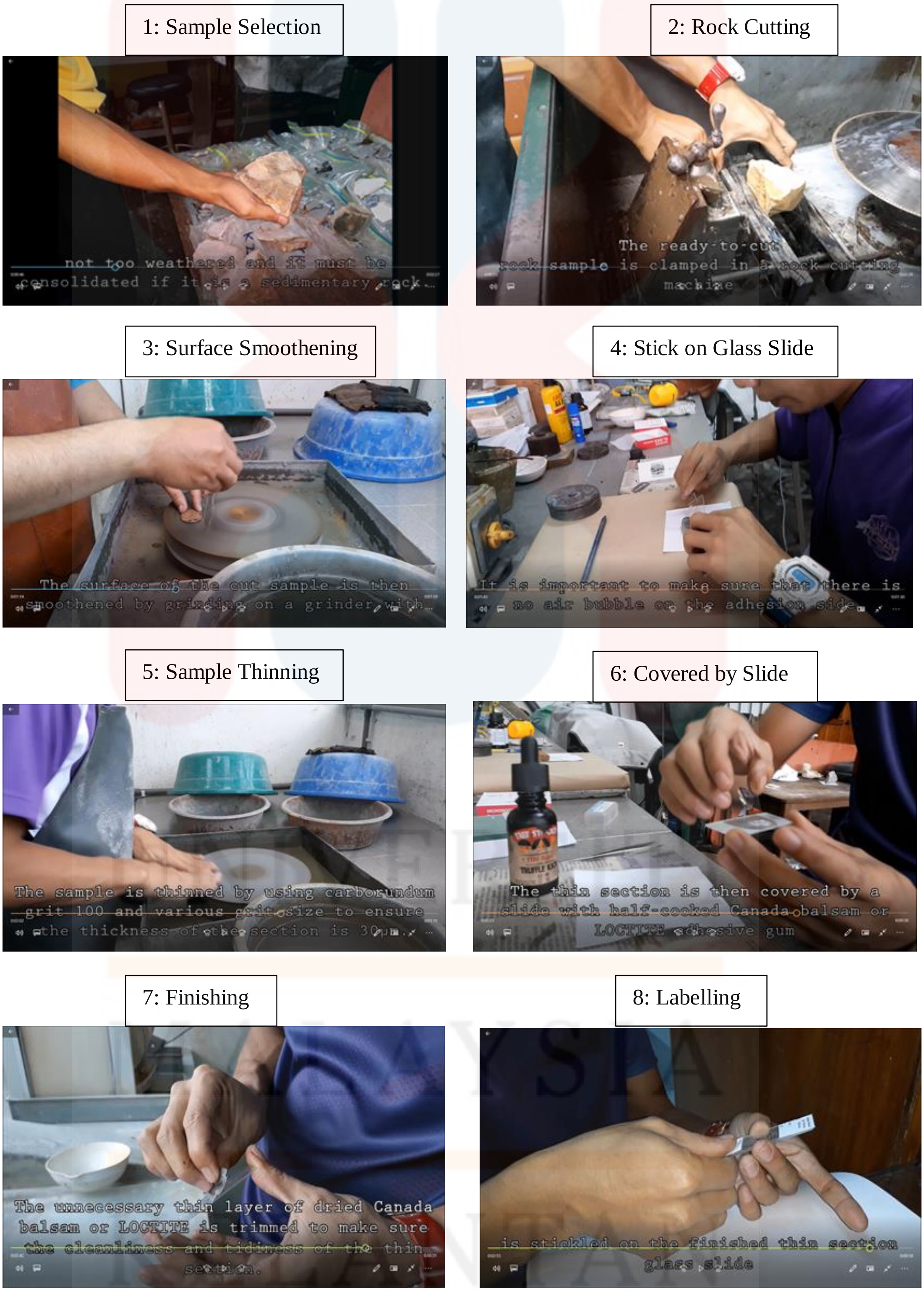


Figure 3.7: Thin Section Procedure.

Sample Pulverization before Sample Digestion

Plant samples were turned into ashes by using oven at 180°C for 24 hours and disintegrated and homogenised in a porcelain mortar and passed through 2 mm sieve.

Soil samples were dried at 60°C, hammered to reduce agglomeration, disintegrated and homogenised in a porcelain mortar and passed through 2 mm sieve. Each soil sample was then be split into three portions using a rotary divider, one of which was archived for further studies and the second was submitted for grain size analysis. The third portion was pulverized in an agate planetary mill to a grain size <0.063 mm, homogenised and divided into bottles to be submitted to the analytical laboratories (Sandström *et al*, 1997). The process is shown in **Figure 3.8**.

Sample Digestion for Atomic Absorption Spectrophotometer (AAS)

The pulverized, homogenized and sieved plant sampl were then dissolved in 5ml hydrochloric acid, HCl in a conical flask before filtered twice by filter paper and syringe filter. The sample was then tri-diluted by using 1:10 ration for sample to distilled water portion by 50 ml volumetric flask and 15 ml falcon tubes.

The pulverized, homogenized and sieved soil sample was then taken 5 grams and is digested by mixture of hydrochloric acid, HCl and sulphuric acid, H_2SO_4 under shaking of 150 rpm for 15 minutes at 27°C. After filtered twice by filter paper and syringe filter, the sample was then tri-diluted by using 1: 10 ratio for sample to distilled water portion by taking 1.5 ml of stock solution to mix with distilled water to 15ml.

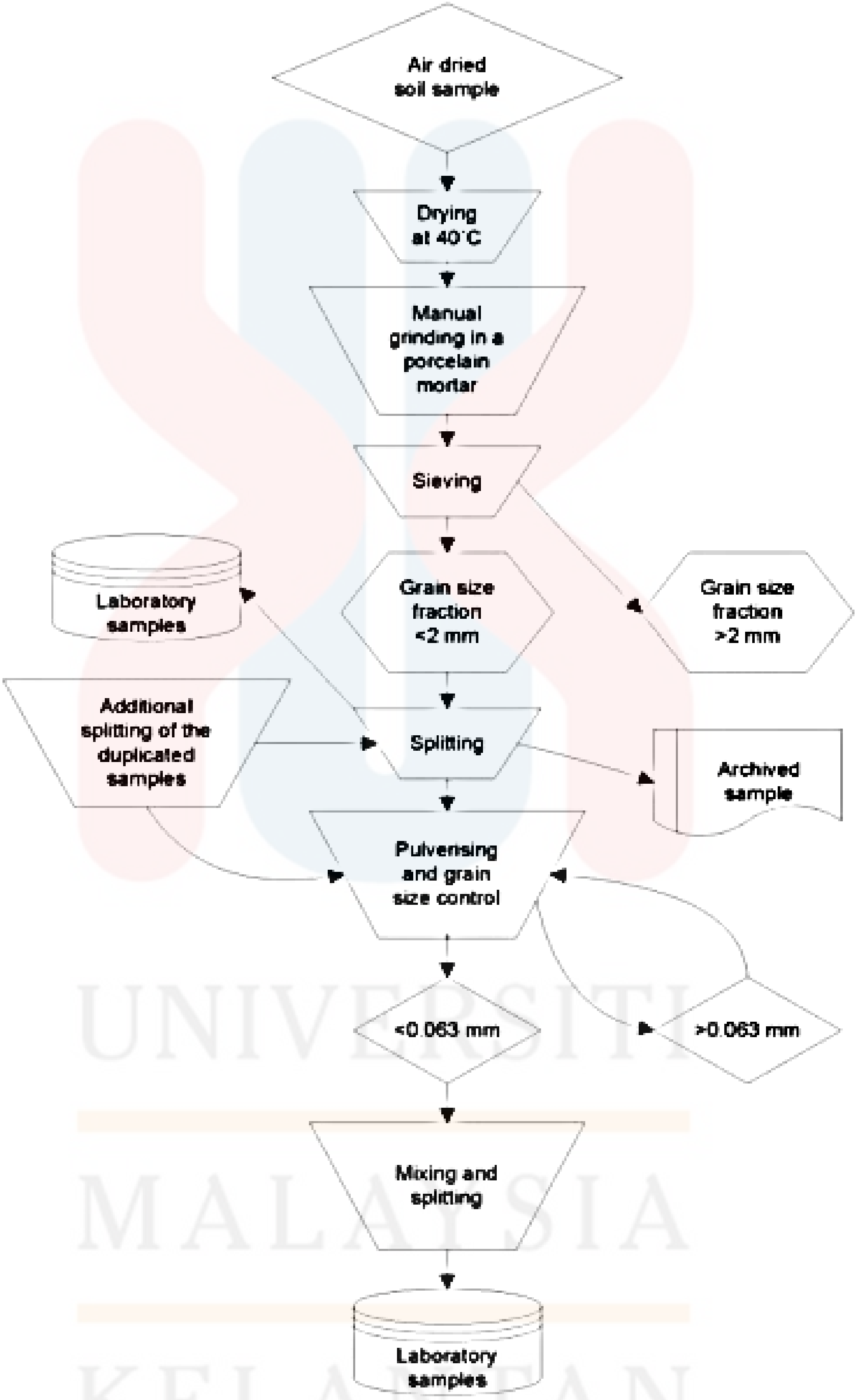


Figure 3.8: Standard method in processing soil samples before AAS, ICP-MS, XRD, XRF and FTIR.

Source: Sandström *et al*, 1997.

Sample Digestion for Inductively Coupled –Mass Spectrometer (ICP-MS)

A simple cold dissolution method was applied for selected elements, viz: As, Cd, Cs, Cu, Mo, Ni, Pb and Sn. In this method, 0.1 g of the soil sample was weighed into a plastic test tube and 1.5 ml of nitric acid and 0.5 ml of hydrofluoric acid was added. The test tube was closed with a stopper, agitated and allowed to stand at room temperature for 48 hours. Deionised water (8 ml) was then added and the solution allowed to stand for a further 48 hours. The test tubes were then agitated and centrifuged and the digest extracted and filtered. The extract was diluted before analysis using a Perkin Elmer Sciex Elan 9000 inductively coupled plasma-mass spectrometer (Sandström *et al*, 1997).

Another digestion method, other than those in cold method was utilised for optimising different elements recovery and limit detection. In this method, 0.2 g of the soil sample was weighed into a Teflon dish and the organic material totally decomposed by evaporating the sample to dryness with 5 ml of 65% nitric acid, followed by the addition of 10 ml of 40% hydrofluoric and 4 ml of 70% perchloric acid and evaporated on a hot plate. The residue was dissolved in 20 ml of 8 mol 1-1 nitric acid and 1 ml of 30% hydrogen peroxide before filtration. The filtrate was saved and the filter paper will be ashed in a platinum crucible. The residue was still fused with 0.2 g of lithium metaborate and 0.02 g of sodium perborate followed by dissolution in 5 ml of 0.8 mol l^{-1} nitric acid. The solutions were combined and made up to 100 ml in 1.8 mol l^{-1} nitric acid. Measurement of these digests was carried out using a Perkin Elmer Sciex Elan 5000 inductively coupled plasma-mass spectrometer (Sandström *et al*, 1997).

Sample Preparation for X-Ray Fluorescence Spectrometry (XRF)

A range of elements was determined by wavelength dispersive x-ray fluorescence spectrometry (WD-XRFS), with Cr and Rh anode x-ray tubes respectively. Pulverized samples were further milled to less than 40 µm particle size. Then 1000 mg per sample was mixed with 5.0 g lithium metaborate and 25 mg lithium bromide, and fused at 1200 °C for 20 minutes. Loss on ignition (LOI) was determined by heating to 1030 °C for 10 minutes. For samples with a LOI greater than 20%, 2.5 g lithium metaborate and 2.415 g lithium tetraborate was used. Pt95-Au5 crucibles and a commercial automatic fluxer (Herzog 12/1500) was used for the fusion (Sandström *et al*, 1997).

Sample Preparation for X- Ray Diffraction Spectrometry (XRD)

The pulverized soil sample was further grinded before being pressed into a pellet and sent for analysis in Bruker X-ray diffraction spectrometric machine for mineral identification. This was done through the software Diffrac.eva by finding the specific minerals through the filters of elements.

Sample Preparation for Fourier- Transform Infra-Red Spectroscopy (FTIR)

The pulverized soil and plant samples were placed on a plate where there's a small circular part for the infra-red light to pass through and the data were collected and analysed by the OMNIC software and library.

3.3.4 Data Processing

Qualitative data came from observation for geological mapping and ecological plotting in rock, soil and plant name and type identification were tabulated and recorded in words. The quantitative data from geological mapping, ecological plotting and geochemical result were processed by using different software.

General Usage

Microsoft Words had been used to in report writing process in fulfilling the format required by the Final Year Project Guideline. Words, as a form of literal data were typed through a keyboard to present on a document format. Microsoft Excel had been used to tabulate data and derive graph automatically from the data keyed in. Microsoft Power Point had been used as a presentation tool.

Geological Mapping

In data processing for geological mapping, the following software is used:

ArcGIS is a well-known geographic information system software for creating and using maps, compiling geographic data, analysing mapped information, sharing and discovering geographic information, using maps and geographic information in a range of applications, and managing geographic information in a database.

In this study, it was used to produce base, geological, geomorphological and geochemical maps through creating an own database on the data collected from fields and chemical analysis. Base map of the study area was produced by the contour, river and stream database obtained from the Geoscience Department of Earth Science Faculty, Universiti Malaysia Kelantan. Each data frame was compiled and overlaid in a way that all data can be shown in a map.

The later mapping data including the geomorphology, rock type, lithology boundary, strike and dip of geological structures which had previously marked by the GPS were transferred and digitized in various shape files. These shape files had been inserted as into different data frame and overlaid into various forms in producing the desirable maps.

GeoRose is software that used for kinematic analysis of joints or in another word, identifying the direction of the principal stress, $\sigma_{1.}$ The field collected strike and dip data with at least 30 frequencies were keyed in into this software and rose diagrams were produced for different joint type. The rose diagrams were used to identify and explain the structural geology and help in interpreting tectonic setting of the study area.

Stereographic projection is stereonet generator for analysing the geological structure such as bedding, fault and folding by inserting the strike and dip data. With the assemblage of points, lines or even contours produced on a streonet after keying in the field collected strike and dip data, the direction of bed tilting, type of fold and the direction of the major force that applied to a particular area were identified and aided in 2D and 3D visualization of geological structures.

Chemical Data

The oxides of soil samples data were identified from XRF analysis, trace elements of plant and soil samples from AAS and ICPMS and minerals through through XRD analysis in software Diffrac.eva, and best matches from FTIR OMNIC Library were all compared to standard and tabulated in Microsoft Excel to generate graph for further analysis and interpretation.

3.3.5 Data Analysis and Interpretation

The relationships, patterns and trends of the rocks, soils and plants in the study area were understood to make data analysis and interpretations. Three main analysis and interpretations in this study were geological, ecological plotting and chemical. Each science has its own nature in analysis and interpretation. In this study, the analysis and interpretation were tried to be maintained as neutral as possible while combining different nature of geological, biological and chemical sciences.

Geological Data Analysis and Interpretation

As stated in the previous section, the geological data after being processed by the geological software generated different diagrams with different patterns. Analysis and interpretation were made based on the visualized information in order to interpret the previous and on-going and predict the future geological events. For rock identification, the minerals were interpreted by referring to optical mineralogy textbooks. Stratigraphy of the study area was interpreted through comparison with the existing literature.

Chemical Data Analysis and Interpretation

After all elements concentration data from AAS, ICP-MS, XRF, XRD and FTIR were analysed and interpreted manually. Elements concentration was analysed in order to find a correlation between the plant and soil in term of their minerals concentration. Geochemical anomaly maps were also produced by creating New Field in Attribute Table in ArcGIS ArcMap in each sampling points to key in the chemical data. Then the following steps were used ArcMap>>3D Analyst>>Iverse Distance Weighting to create geochemical anomaly map of each element. The anomaly maps were then produced by Overlay>>Weighted Sum by assigning weightage 1.0 for each previously produced IDW raster for fair integration.

CHAPTER 4

GEOLOGY

4.1 Introduction

Geology of the study area is presented in this chapter as a result of geological mapping. This chapter is composed of geomorphology, lithostratigraphy, structural geology and historical geology. Due to the low accessibility in this study area of high vegetation coverage, amount of exposed rock are limited thus interpretation has been done based on the limited observable outcrop.

4.1.1 Brief Content

In this chapter, the general condition of the study area is described based on its accessibility which is the easiness in accessing this study area and by mean of different type of transportation; settlement which is the living area of the residents in this area; traverses and observations which is the path of investigation that has been done in this area. In term of geomorphology, classification has been made; weathering and drainage pattern are also discussed. Lithostratigraphy has the the explanation of each stratigraphic unit and its position. Structural geology shows the cleavage, vein, joint, fault, fold and mechanism of structure. Historical geology of the study area has also been proposed through the field evidence.

4.1.2 Accessibility

The overall accessibility of the study area is low as most of the area is covered by thick forest which can be clearly seen in **Figure 4.1**. The only accessible route is the route to the mining and logging sites which some of the routes are even in restricted area where there are blockers which require permission from the authorities and the management team of the mining, logging and plantation companies to access that particular area such as in **Figure 4.2**.

As all the routes in the study area are in off-road condition, in order to access the rough route, high duty 4 wheels vehicles are needed as shown in **Figure 4.3**. Despite that, there are many routes are blocked by fallen bamboo trees because of the natural grazing activities by the original natural habitants--- wild elephants in this area, shown in **Figure 4.4**. Removing these natural "road blocks" along the route has been time and energy consuming and complicate people with sensitive skin towards the bamboo leaves.

During the rainy season which is when this project had been carried out, the routes had been too lumpy and become very difficult to be driven through even by heavy duty 4 wheels vehicles or even walked through. During the drier season or long period with less precipitation, the roadside will be very dusty as most of the heavy vehicles uplift the pulverized rock to the roadside plants and contribute to a low air quality. Thus it is advisable not to carry out geological mapping during rainy season in this area and also wear some masks during drier season for personal safety and health. Boat may be a less popular alternative transportation which will travel through the main river, Sungai Sokor as not all places are connected by the Sokor – Taku Offroad.

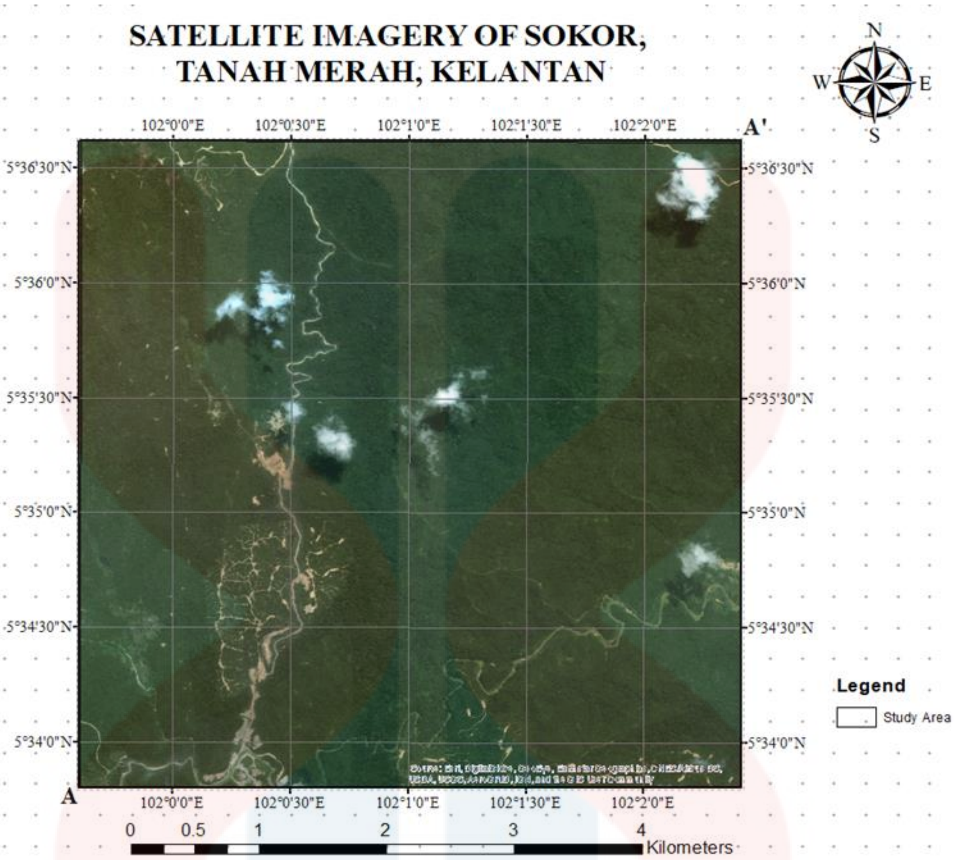


Figure 4.1 clearly shows the study area is densely covered by thick vegetation thus contributing to high biodiversity, limited accessibility and settlement.

Figure 4.2 shows process of getting permission of the company staffs are needed in order to access the relatively accessible route in the study area.

Figure 4.3 shows heavy duty 4 wheels vehicle such as Hilux is very important for transportation in the study area due to the hilly and off road condition.

Figure 4.4 represents many routes in the study area which are blocked by fallen bamboo caused by elephants' grazing activity which has worsen the original low accessibility this area.

4.1.3 Settlement

There is no housing area for civilians in the study area as this is part of the Sokor Taku reserve forest. There are wooden made camps or dormitories for the workers in the mining, logging and plantation area which are usually being fenced and guarded by security officers as shown in **Figure 4.5**. Water, food and daily needs are all supplied through the heavy duty 4 wheels transportation by the own company as there is no water piping system and groceries in the area.

Two mining companies located at the peripheral area of the study area are CNMC Gold Mining and Prima Warisan Mining. Thus temporary residents of this area are mostly staffs and workers from these companies who rarely exit this area. The plantation workers are mainly the nearby villagers and they usually come back and ford to this area daily by mean of motorcycles. Water and food are mostly self-prepared by the workers.

Telecommunication services from any providers are not accessible in this study area except in bare high region in the study area with coordinates N 05° 36' 06.0" E 102° 00' 47.2" of elevation 247 metres as shown in **Figure 4.6**. Thus, people working in this area are isolated from the outer world with no access to internet thus any news and important information. Among the staffs and workers of the companies especially those from mining companies are using radio communication or commonly known as walkie-talkies. This communication system is usually used in administration and operational processes.

Figure 4.5 is an example of settlement of gold mines that is mostly fenced and security guarded to avoid invasion of irrelevant individuals. In this particular site, there is a long way of the from the staff dormitory from this gate. Due to confidential issues, the photo of settlement is not shown here.

Figure 4.6 clearly shows the high bare region in the study area which is the only location where telecommunication services and even the internet can be accessed.

4.1.4 Forestry or Vegetation

95% of the study area is made up of the thick forest area as shown previously in **Figure 4.1**. The forest is originally a dipterocarp forest with part of it becomes secondary forest after logging activities as there is abundance of floor plants which has complicated any traversing in this area. The study area itself is located in a reserve forest named Hutan Simpan Kekal Sokor Taku under the regulation of Kelantan State Forestry Department. The deforested zone in the map is either mining or logging site or the routes towards these areas.

There are many endemic flora and fauna species in the study area. Some fascinating fauna such as elephants, boars, tigers were seen or heard while this project was being carried out. Elephant dungs are ubiquitous in the study area as shown in **Figure 4.7** and the footprints of boar and tiger are recorded in **Figure 4.8**. Some of the staffs from nearby mining companies have claimed that they have seen bears from this study area during exploration.

It is obvious that the biodiversity in the study area is greatly affected by the deforestation activities for the production of the commercial woods or exploiting the precious minerals for economic development. There are several localities in the study area which has been set as logged timber collection points. An example is shown in **Figure 4.9**. This is place where loggers tag the diameter and height of the trees and a collection point for the trucks to transport to be processed in the wood processing factories. These are the bare land area shown by the satellite image in **Figure 4.1**.

As one of the permanent reserve forest under the Forestry Department of Kelantan, the study are has been classified as TLC zone or Latex Timber Clone Plantation (LTC) as an initiative to recover the timber-logged land within 55 years to ensure the sustainable development and production of commercial timber. Not all area of the forest can be developed as Latex Timber Clone Plantation only those which has been logged, sandy clay soil, top soil not less than 15cm, slopes less than 35° to avoid mass movement, elevation below 600 metres above sea level, in cluster form.

With ecological plotting that has been done along the roadside as shown in Figure 4.10, the most dominant roadside plant species in the area is fern which is a good hyper-accumulator of any elements from the soil because of its vascular system.

Figure 4.7 shows the abundance of elephant dungs in the study area indicating presence of elephants. The photo was taken at N 05° 36' 04.993" E 102° 00' 47.861".

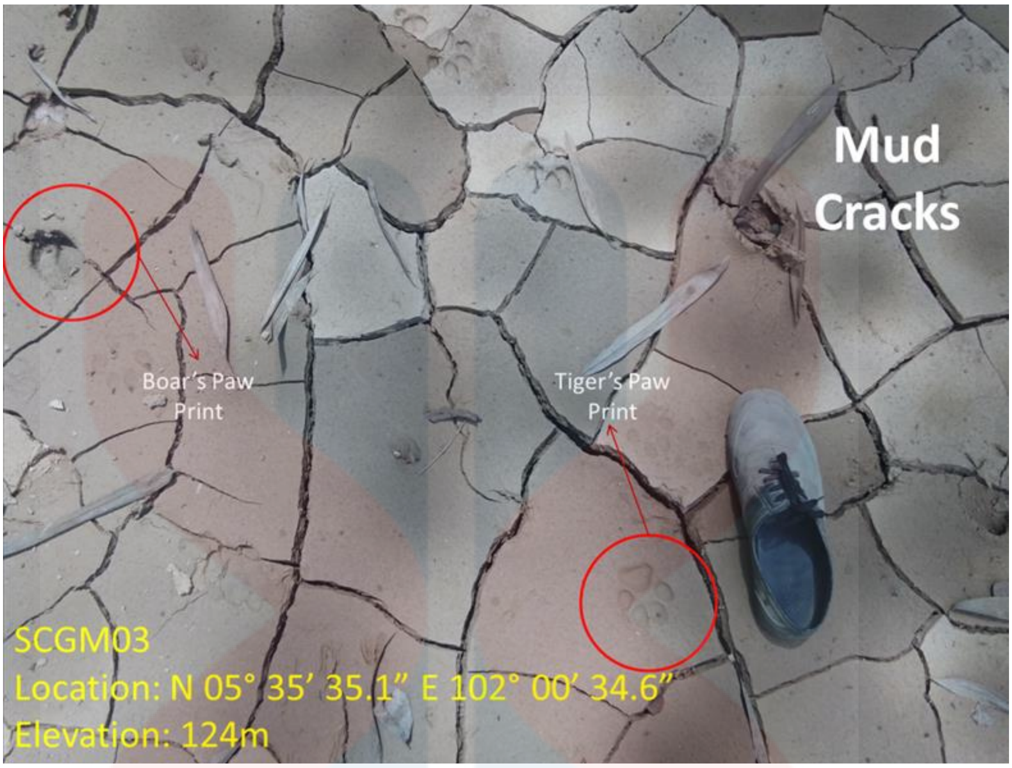


Figure 4.8 shows the presence of wildlifes such as boars and tigers in the study area. The photo had been taken at N 05° 35' 35.1" E 102° 00' 34.6" with elevation 124 metres.

Figure 4.9 shows one of the logged timber collection points in the study area at N 05° 34' 18.569" E 102° 00' 22.226".

Plant Type	Coverage (%)
Fern	50
Bamboo	30
Network Veined Leaves Plants	10
Small Leaves Plants	10

Figure 4.10 shows the dominant roadside plant species as a result of ecological plotting in the study area.

4.1.5 Traverses and Observations Map

Traversing had been carried out in order to determine the geological structures and stratigraphic boundaries of the study area and also for plant screening. Traversing has been difficult in this region as many places in the study area cannot be entered directly from the roadside as they are mostly thick secondary forest with steep valley where the strong timber trees had been logged. Thus it is very not favourable and extremely dangerous to carry exploration by using roping to climb down the hills. Detailed observation has been made along the traversable path, as shown in **Figure 4.11**.

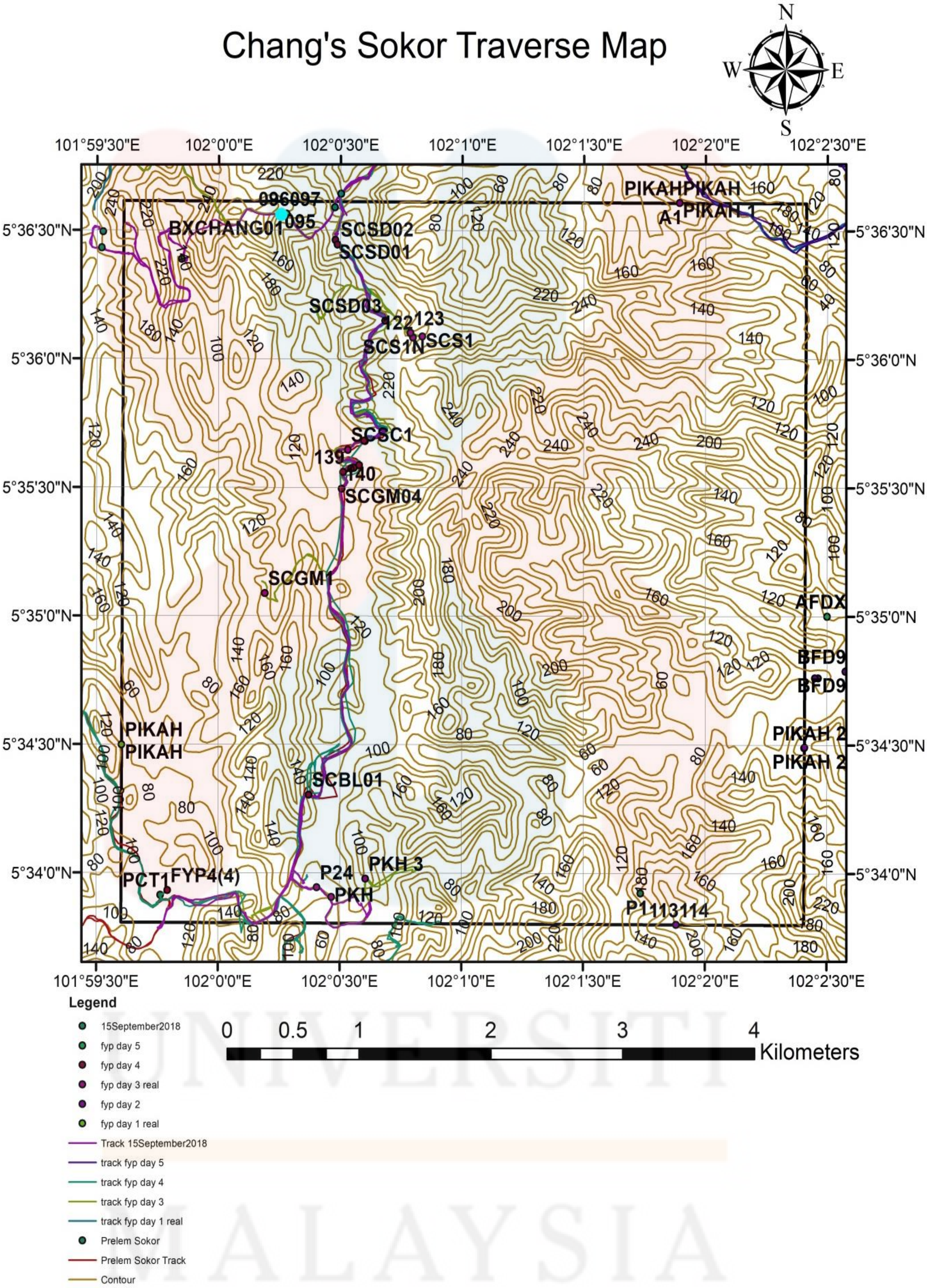


Figure 4.11 shows the traverse map in the study area with very limited accessible localities.

4.2 Geomorphology

Geomorphology is the study of the shape of the earth and the processes that contribute to current landscape. Geomorphology of a particular place can indicate its palaeo-environment and also its current environment. Classification can be done based on the altitudes and main agents shaping the rock thus contributing to its current geometrical properties.

4.2.1 Geomorphologic Classification

This study area can be classified as an undulating hilly area as shown in the **Figure 4.12**. The lowest elevation regions are made up of river and streams which most probably are of alluvium deposits sourced by weathered products of the surrounding hills. Two main geomorphologic classifications are applied: morphometry and morphogenesis. Geomorphological observations were along the traverses. **Table 4.1** summarizes the geomorphological observation of the study area in term of morphometry and morphogenesis.

Morphometry deals with the geometry of the landscape, including slope, elevation, relief, top shape, valley shape and slope shape. Morphogenesis on the other hand deals with how this geometry can be formed through observation on erosion, ground motion, sedimentation, weathering types and rate, simple details of soil and river. Lithology, land cover, land use, age of area and formation are added in order to a relationship to the current geomorphology.

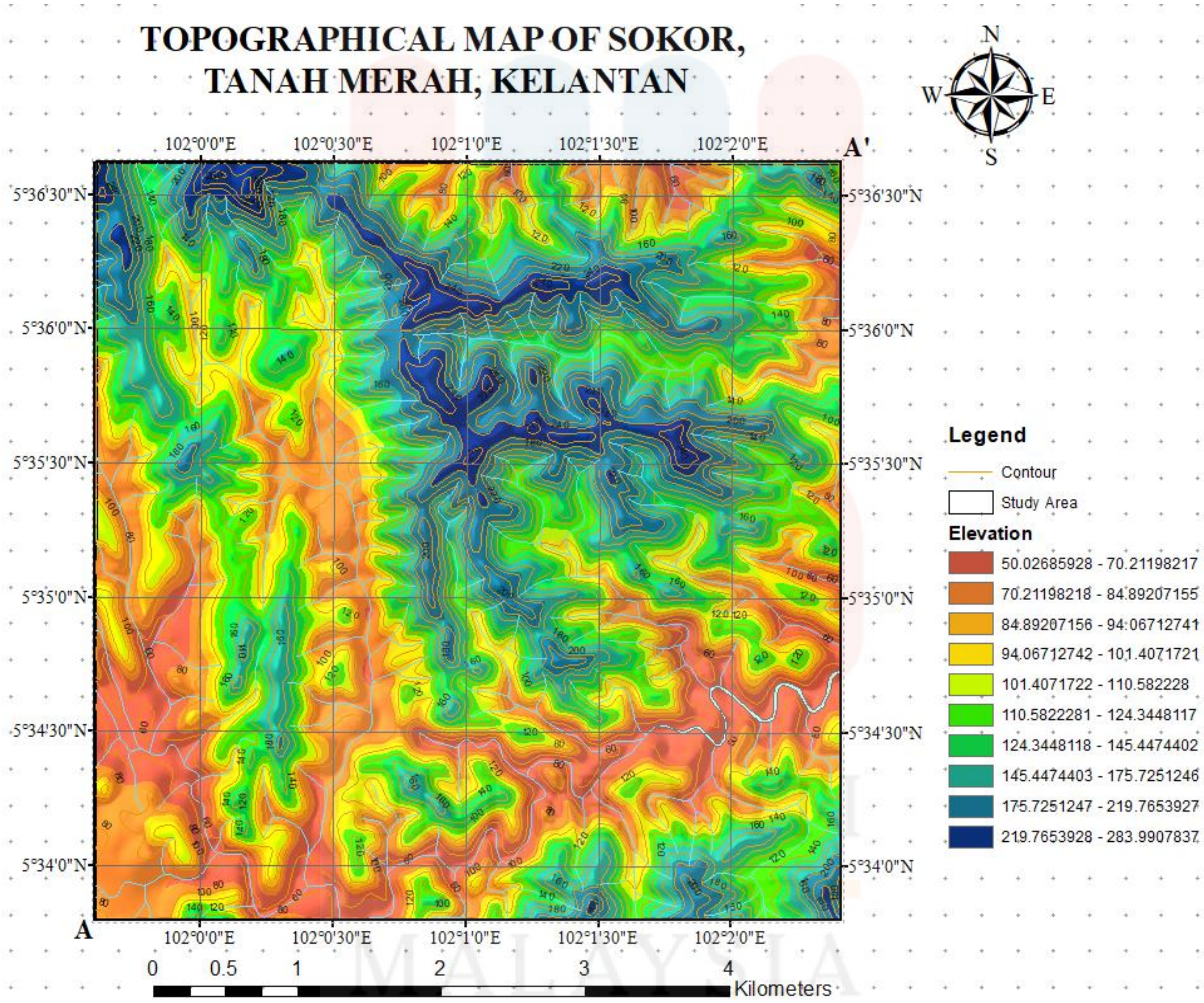


Figure 4.12 shows the topographical map or Digital Elevation Map (DEM) of the study area.

Table 4.1 is the geomorphological observation of the study area.

<table>
<tr><th colspan="3" rowspan="2">GEOMORPHOLOGY ASPECT</th><th>LANDSCAPE</th></tr>
<tr><th>Study Area</th></tr>
<tr><td colspan="3">AREA</td><td>5 km^2</td></tr>
<tr><td rowspan="6">MORPHOMETRY</td><td colspan="2">Slope</td><td>Steep slope towards the hill foot</td></tr>
<tr><td colspan="2">Elevation</td><td>Between 50 to 285 metres</td></tr>
<tr><td colspan="2">Relief</td><td>Hilly</td></tr>
<tr><td colspan="2">Top shape</td><td>Long smooth hemispherical shape</td></tr>
<tr><td colspan="2">Valley shape</td><td>Between V to U-shape</td></tr>
<tr><td colspan="2">Slope shape</td><td>Convex</td></tr>
<tr><td rowspan="13">MORPHOGENESIS</td><td colspan="2">Erosion</td><td>Sheet, rill, gully</td></tr>
<tr><td colspan="2">Ground motion</td><td>Rarely landslide and rock fall, greatly retained by vast vegetation</td></tr>
<tr><td colspan="2">Sedimentation</td><td>Sandy sediments along the river banks</td></tr>
<tr><td colspan="2">Weathering types</td><td>Physical, Chemical, Biological</td></tr>
<tr><td colspan="2">Rate of Weathering</td><td>High but metamorphic rock are more resistant</td></tr>
<tr><td rowspan="3">SOIL</td><td>Types</td><td>Clayey, Sandy, Ultisol, Oxisol</td></tr>
<tr><td>Thickness (m)</td><td>Thin to intermediate organic layer (O horizon)</td></tr>
<tr><td>Colour</td><td>Brownish, Yellowish, Purple</td></tr>
<tr><td rowspan="5">RIVER</td><td>Genetic Type</td><td>Epigenetic</td></tr>
<tr><td>Type</td><td>Single-channel river</td></tr>
<tr><td>Cross section</td><td>Between V to U-shaped due to erosion and sedimentation</td></tr>
<tr><td>Channel pattern</td><td>Meandering River , Trellis Streams</td></tr>
<tr><td>Age</td><td>Old to intermediate</td></tr>
<tr><td colspan="3">Lithology</td><td>Argilitic and calcareous units</td></tr>
<tr><td colspan="3">Land cover/ Vegetation</td><td>Dipterocarp forest (a type of tropical rainforest)</td></tr>
<tr><td colspan="3">Land-use</td><td>Timber logging, Plantation and Mining, LTC</td></tr>
<tr><td colspan="3">Age of area</td><td>Permian to Upper Triassic</td></tr>
<tr><td colspan="3">Formation</td><td>Gua Musang Formation and Telong Formation</td></tr>
</table>

Morphometry

The slopes of the study area are majority steep towards the hill foot and in convex shape; the elevation of the study area is between 50 metres to 285 metres, as seen in the **Figure 4.12**. The lowest elevation area is in the river and stream area which able to be a water catchment area. Generally, the whole area is of hilly relief thus making traversing difficult in this area. The hill tops are in long smooth hemispherical shape as shown in **Figure 4.13**, which is formed by the erosion of the argillitic regolith, diffusive movement of hill top soil by downhill creep. The valley shape is between V to U shape, no obvious pointy front has been observed.

Figure 4.13 shows the geomorphological view at coordinates N 05° 36’ 06.10” E 102° 00’ 47.4” of elevation 247 metres.

Morphogenesis

Two types of erosion have been happening in the study area: sheet and rill erosion. Sheet erosion is the surface runoff of soil at a minimum level as shown in **Figure 4.14**; rill erosion can be seen through the occurrence of small shallow channels on top of soil or rock as shown in **Figure 4.15**. Erosion has been enhanced by the deforestation and anthropogenic activities such as slope cutting and development of land without proper planning and management.

Figure 4.14 shows sheet erosion at N 05°36’52.929” E 102°0’55.467” at elevation of 69.08m from a steep sloped road.

Figure 4.15 shows a rill erosion at N 05° 36’ 33.8” E 102° 00’ 16.6” of elevation 237m.

Ground motions or mass movements in the study area are mainly downhill creeps, slight landslides and rock falls. Downhill creep is the slow motion of the soil towards the foot of hill. It generally happens at every hill slope, but the process has been decelerated by the retention through the plant roots. Thus the deforested exposed slope is more susceptible to mass movement and the ground motion is comparatively in a faster velocity than that of vegetated slope.

Landslide has rarely happened at the study area but some slopes which are not well engineered are in risk of landslide either wedge or topple failure owing to the slope cutting which does not take dip angle and dip direction of the rock strata into account during planning and execution. Most of the mass movements including liquefaction are unlikely to happen in this area as most of the slope surfaces are covered by the vegetation which means the soil is hold by the root system of the vegetation. Sedimentation of the study areas is the deposit of the weathered and eroded materials from the hill regolith or carried from the higher elevation by the river and streams. The sediments are mainly sandy along the river banks and also the streams.

Soils in the study area are mainly clayey and sandy. The dominant soil type of the area is oxisol and ultiosol. Oxisol is the soil with iron content thus it appears at red to purple colour. Ultisol is soil with high amount of clay minerals such as kaolinite, montmorillonite and dickite thus it shows yellowish brown colour. Both soils are shown in **Figure 4.16**. Throughout the box, the organic layer or O horizon varies from thin to thick depends on the overlying vegetation cover.

Figure 4.16 shows the main soil types in the study area: Oxisol and Ultisol. The features with higher relief in both of the photo is quartz which is chemically and physically more resistant to weathering processes than other minerals.

4.2.2 Weathering

Due to the humidity content because of high precipitation and high temperature, weathering process is prevalent in tropical region. The exposed rocks and soil in the study area are more susceptible to weathering due to the more favourable conditions as stated. Physical, chemical and biological weathering are the three main types of weathering and always enhance each other through increase of total surface area, as seen in **Figure 4.17**.

Physical weathering is the physical disintegration of rock. The fluctuation of surrounding temperature during transition of day and night time changes the volume of outer layer of the rock thus creating pressure to the internal core. The continuous expanding and shrinkage makes the outer layer weak and fall apart from the rock.

Rocks of the river bank are exposed to hydraulic pressure and the flow of river. Cleavage between phyllite has been more favourable for physical weathering.

Chemical weathering such as oxidation can be seen clearly from the iron oxide which made the rock and soil in red colour. The high precipitation amount, humidity content and temperature have enhanced and accelerated the chemical weathering. Most of the rocks in the study area have undergone this weathering thus making petrographical analysis very difficult. As seen in **Figure 4.16**, quartz are more chemically and thus physically more resistant than other minerals.

With high coverage of vegetation as seen in **Figure 4.1**, rocks in the study are undergoing biological weathering such as the pressure from the growing tree roots. Some burrowing animals such as mice also contribute to the biological weathering of rock. Microorganism such as bacteria which respires by certain source minerals are contributing to biological weathering as well.

Figure 4.17 shows three of physical, chemical and biological weathering is constantly happening in the study area at waypoint BXCHANG01 with coordinates of N 05° 36' 33.8" E 102° 00' 16.6" and elevation of 232 metres.

4.2.3 Drainage Pattern

Drainage pattern is the general shape of the streams in an area. Drainage pattern can indicate the rock type of an area due to the resistivity of rock towards running water.

The hilly study area is mainly made up of trellis streams where surface alternates between resistant and erodible material as between phyllite and soil which turn into sub-dendritic patterns because of uniform material.

The main river, Sungai Sokor is a meandering river from former epigenetic type which is formed by erosion of valley and currently cooperates with sedimentation at point bar. It evolves during flood because of the easily erodible soil. Thus the area around Sungai Sokor is the flood basin.

The shapes of the streams and river are shown in the drainage pattern map in **Figure 4.18**. The watershed region has also been illustrated in **Figure 4.19** to show where the water catchment areas are. The watershed regions are always the area with lower elevation.

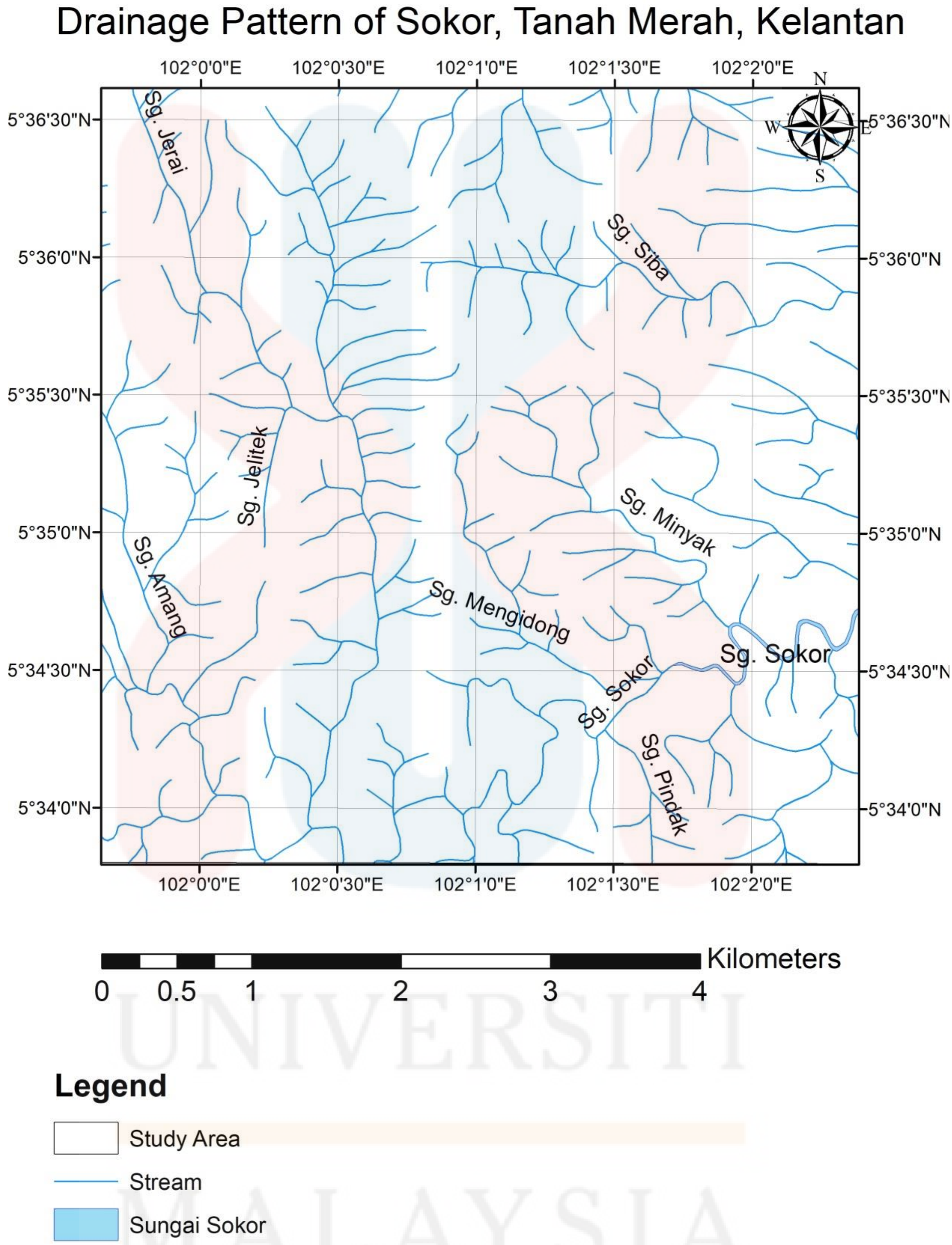


Figure 4.19 is the drainage pattern map of the study are which shows the main river is a meandering river and the streams are in trellis pattern.

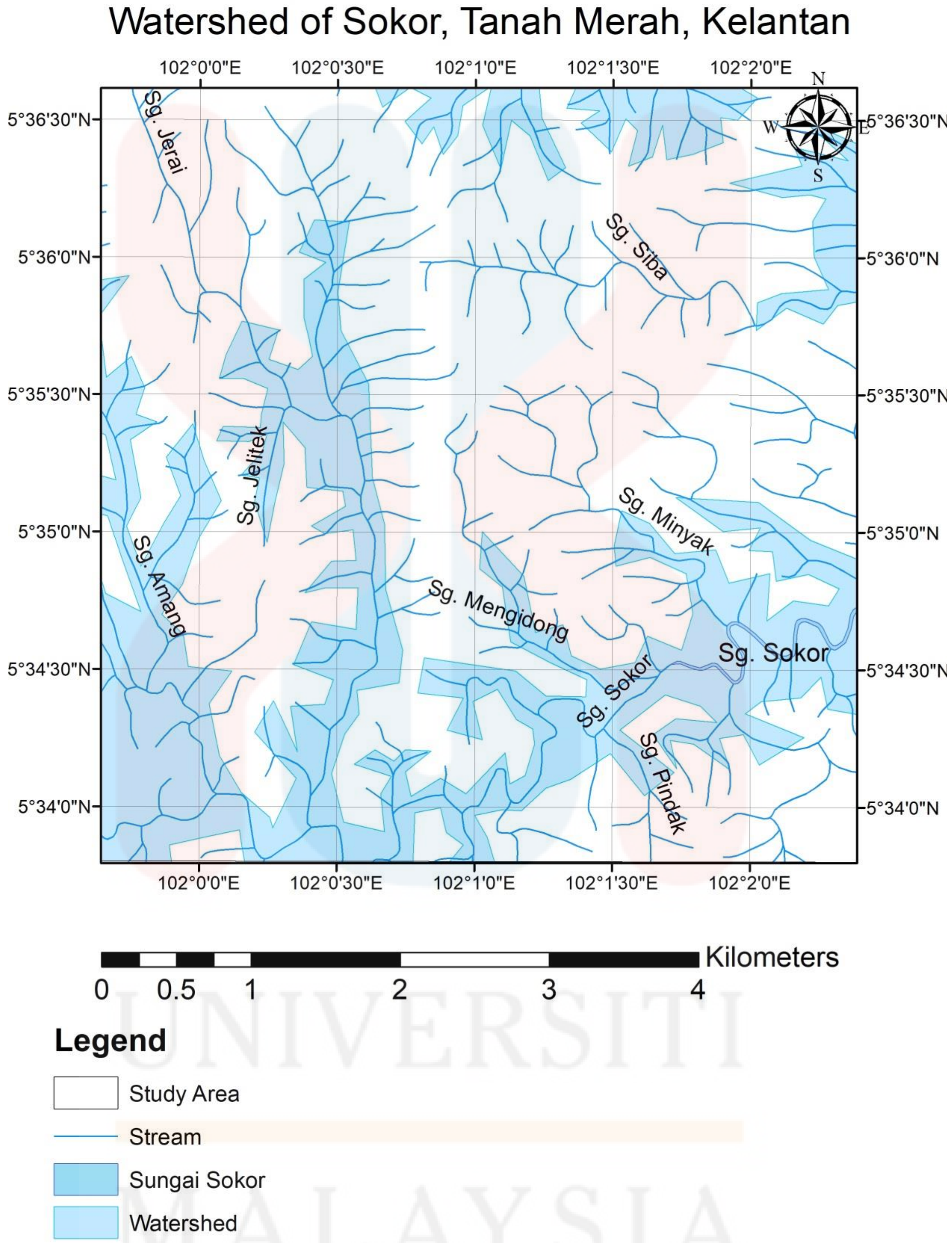


Figure 4.20 shows the watershed map of the study area or also known as water catchment area.

4.3 Lithostratigraphy

In this section, rock layers of different formation are shown in this section through stratigraphic column, and the field and petrographic analysis of each of the rock found in the study area. A geological map is shown is **Figure 4.20**.

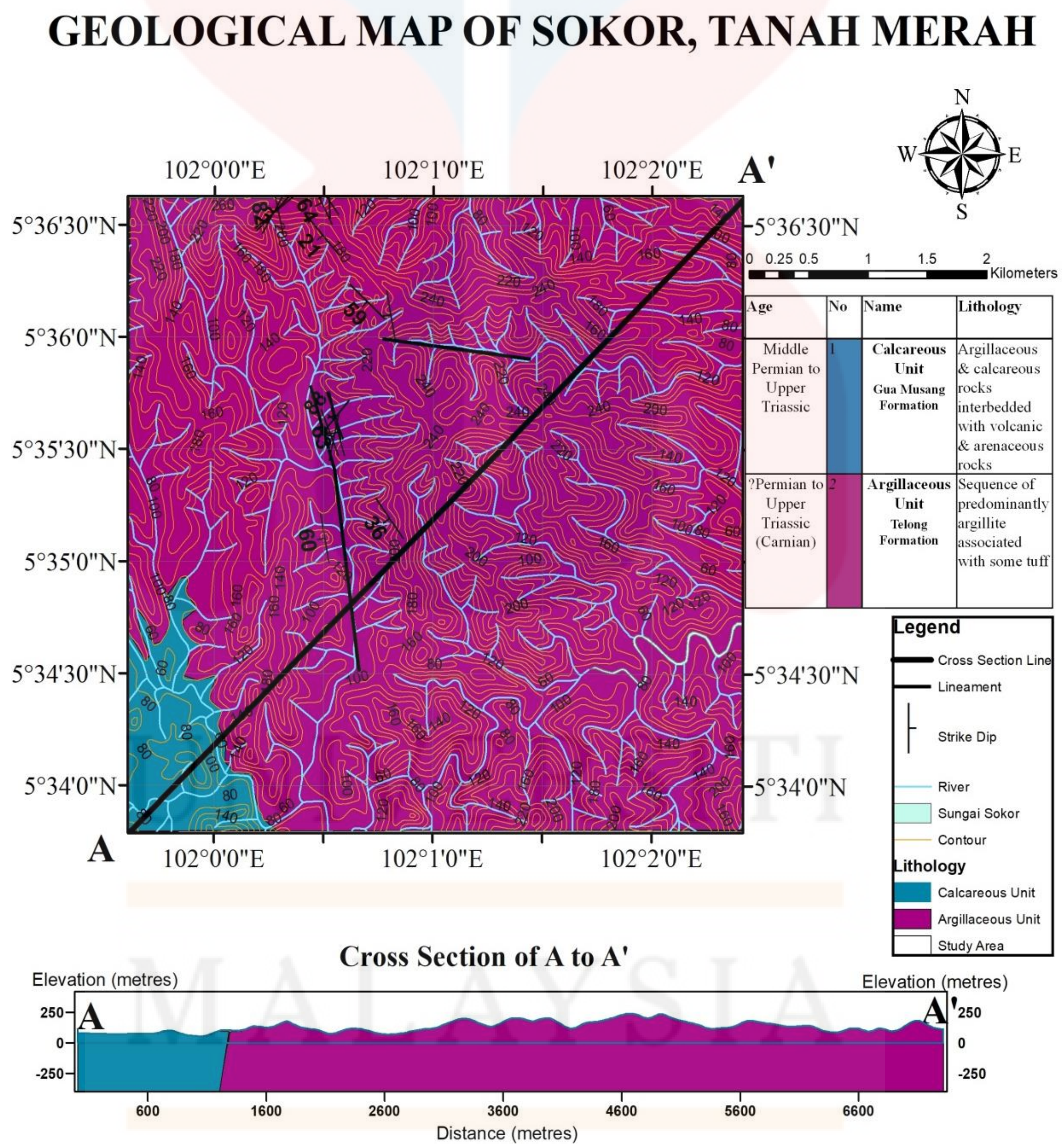


Figure 4.20: Geological Map of the study area.

4.3.1 Stratigraphic Position

Through field observation, two main groups of lithology have been found in the study area: dominant by argillaceous unit and a small portion of calcareous unit. In term of elevation as shown in **Figure 4.20**, calcareous unit from Gua Musang Formation lays unconformably in the argillaceous unit which believed to be from Telong Formation as stated in the previous literature.

The calcareous unit are not pure calcareous but mixed or interbeded with argillaceous, volcanic and arenaceous rock. The calcareous unit interfringes the argillaceous unit which is predominantly formed by argillite with some tuff and has undergone metamorphism into phyllite. For simplicity the calcareous unit has been placed above the argillaceous unit as shown in stratigraphic column in **Figure 4.21**.

Age	No	Name	Lithology	Depositional Environment
Middle Permian to Upper Triassic	1	**Calcareous Unit** **Gua Musang Formation**	Argillaceous and calcareous rocks interbedded with volcanic and arenaceous rocks	Shallow marine shelf deposit, with active volcanic activity
?Permian to Upper Triassic (Carnian)	2	**Argillaceous Unit** **Telong Formation**	Sequence of predominantly argillite associated with some tuff	Stable shallow marine environment with occasional supply of fine pyroclastic material

Figure 4.21: Stratigraphic Column found in the study area.

4.3.2 Unit Explanation

Argillaceous Unit

Argillaceous unit in these are mostly metamorphosed into the phyllite. From the geological map, other than the lower left corner, the whole area is covered by argillaceous rock. The complete set of argillaceous rocks can be observed in **Figure 4.22**. Since most of the rock are very weathered and till undergoing weathering processes, petrographic analysis through thin section observation has been impossible. The weathered rocks grains were too loose and the rock friable during thin section preparation. As an alternative, the rock samples have been placed carefully below a stereoscope for surface observation.

Phyllite is a low degree foliated metamorphic rock after slate. It has been exposed to relatively lower temperature, pressure and chemical alteration as compared to its counterparts of higher metamorphism—schist and gneiss. Phyllitic cleavage due to strong parallel alignment of mica within phyllite made it easily to be split into slabs as shown in **Figure 4.23**. From observation, it can still be traced that the protolith or the parent rock are from siltstone and shale with the mixture of tuff.

Figure 4.22 shows an outcrop containing all the argillaceous rocks in the study area at SCS01 with coordinates of N 05° 36’ 06.0” E 102° 00’ 47.2”and elevation of 247 metres.

Figure 4.23 shows phyllite which has been split into slabs due to the strong parallel alignment of mica within phyllite. Upon careful observation, this figure also shows the differential chemical weathering making the grey phyllite interbedding the red phyllite. The grey phyllite is more resistant because of higher quartz content and the red phyllite showing the abundance of iron oxide. Iron nail as scale.

The phyllites, based on field observation, are originally grey in colour as shown in **Figure 4.24**. But most of the phyllites in the field are red in colour as shown in **Figure 4.25**, anticipating a high content of iron oxide in the rock which has undergone chemical weathering. This is confirmed by the brownish minerals seen on the thin sections made. Both grey and red phyllites split into slabs upon knocking off by a geological hammer.

The phyllite thin section, as shown in **Figure 4.26** had been seen under polarized microscope but because of high iron content, the minerals are not able to be identified. Stereoscope had been used to see the foliation or crenulation of the phyllite, as shown in **Figure 4.27** and thus can be concluded as phyllite. All argillaceous rocks found in the study area after observation under stereoscope are confirmed to have become phyllite as shown in **Figure 4.28**. Minerals such as quartz, mica and chlorite can be seen in the samples.

Figure 4.24 shows the grey phyllite occurrence in waypoint BXCHANG01 with coordinates of N 05°36' 34.0" E 102° 00' 15.4" with elevation of 237 metres.

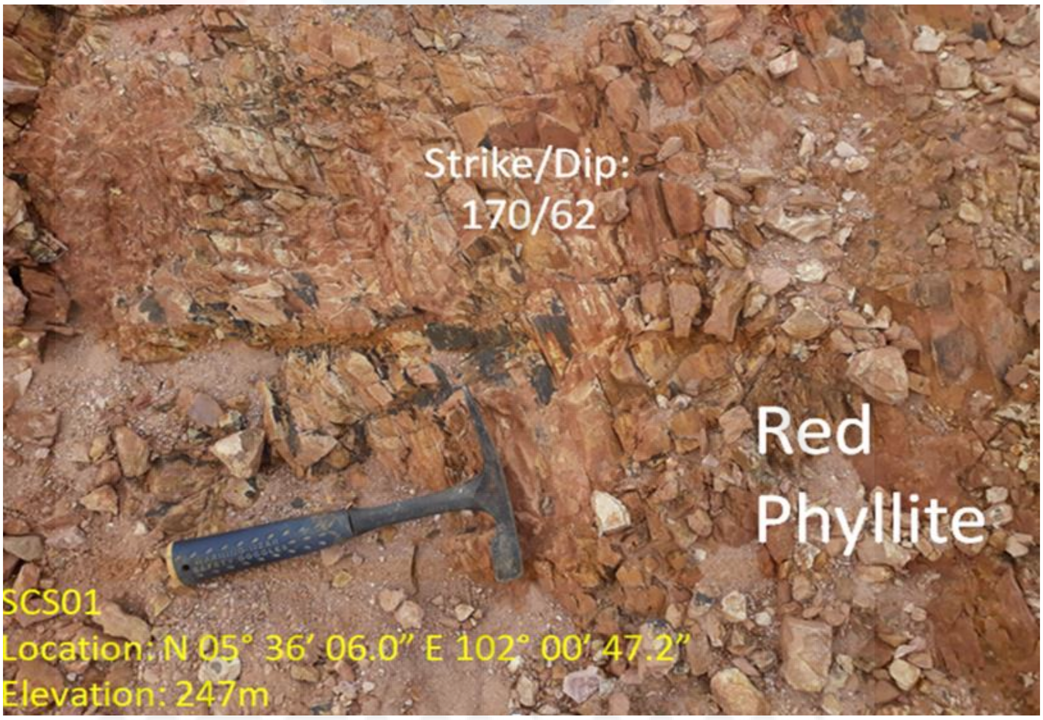


Figure 4.25 shows the red phyllite occurrence in waypoint SCS01 with coordinates of N 05°36' 06.0" E 102° 00' 47.2" with elevation of 247 metres.

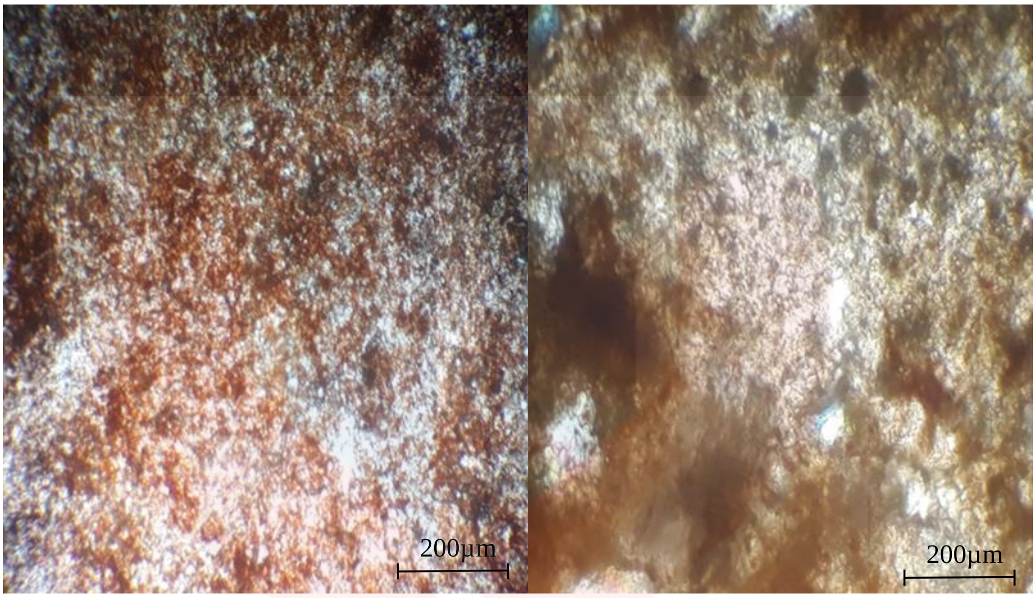


Figure 4.26 shows the phyllite and tuffaceous phyllite thin sections are too weathered where the brown colour grains are iron oxide, even foliation is not visible under PPL x10, the vitreous anhedral and euhedral minerals can be quartz.

Figure 4.27 shows red phyllite under stereoscope x 0.7. Crenulation and phyllitic foliation can be seen clearly under the stereoscope.

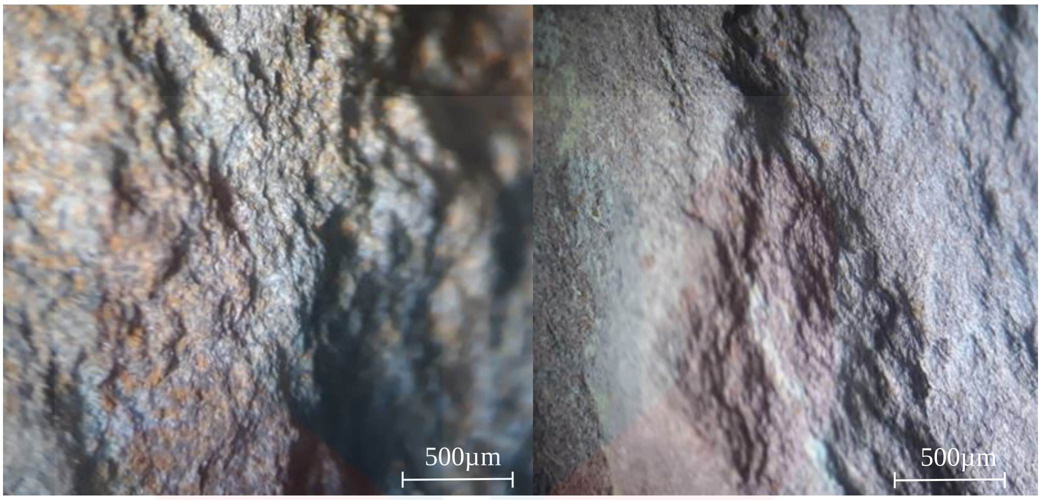


Figure 4.28 shows other phyllite samples found in the study area under stereoscope x 0.7.

Calcareous Unit

Calcareous unit found is concentrated at the low left corner of the study area. The primary indicator of the calcareous unit is it reacts with HCl to produce effervescence of carbon dioxide. The calcareous unit or limestone found in the study area is interbedded with the mudstone. In the study area, limestone outcrop only found in the middle of stream as shown in **Figure 4.29**.

c

Figure 4.29 shows limestone interbedding grey mudstone outcrop in the study area.

Limestone interbedding mudstone thin section was observed under plane polarised light (PPL) with the magnification of 10 times, as shown in **Figure 4.30**. The colourless vitreous calcite minerals are of rhombohedra cleavage. As an uniaxial mineral of high birefringence, optic orientation of calcite is difficult to be determined. The calcite mineral, with rotation, shows a very high relief and high order colours under cross polarised light (XPL). The dark layer of mudstone, as seen under the microscope should be name as lime mudstone as the inclusion of calcite in the mudstone.

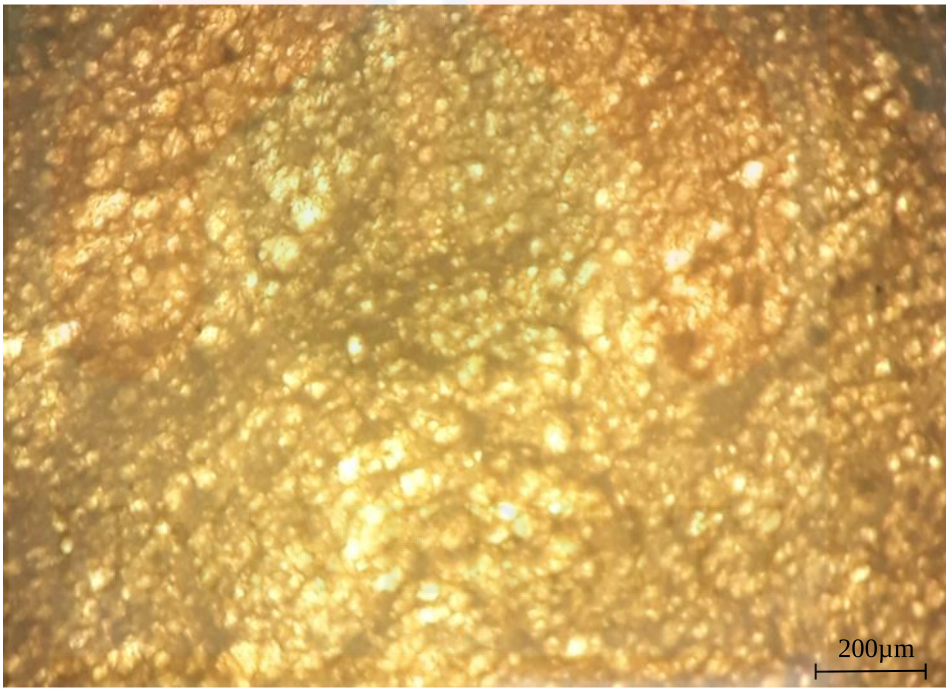


Figure 4.30 shows limestone interbedding mudstone thin section under PPL x10 with abundant of calcite.

4.4 Structural Geology

In this section, the geological structures: cleavage, vein, joint, fault and fold are discussed and the mechanism of structures were interpreted based on the field data collected through structures visualization by stereonet and Visible Geology.

4.4.1 Cleavage

Cleavage is a planar feature formed by deformation or metamorphism. This feature occurs in the fine grain rock through diagenesis as secondary foliation in deformed or deforming metamorphic rock. Since the rocks in the study area are mostly foliated metamorphic rock, phyllite, cleavage are prevalent. The rocks are broken into layers when knocked off by a geological hammer, and the foliation can be observed clearly. The perfectness of cleavage based on the degree of foliation and the minerals contained by the rock. Cleavage of phyllite is shown in the previous section of lithologic unit explanation.

4.4.2 Vein

Vein is a distinct mineralised structures in a rock. Quartz vein is abundant in the study area as a result of hydrothermal alteration by the magma intrusion. Many quartz veins are surrounded by a thin layer of black material which is believed to be iron oxide or mixture with manganese. Some quartz veins are the results of infilling the joints thus following the shape of joints as shown in **Figure 4.31**. Some quartz veins are more irregular as they are following the shape of cracks.

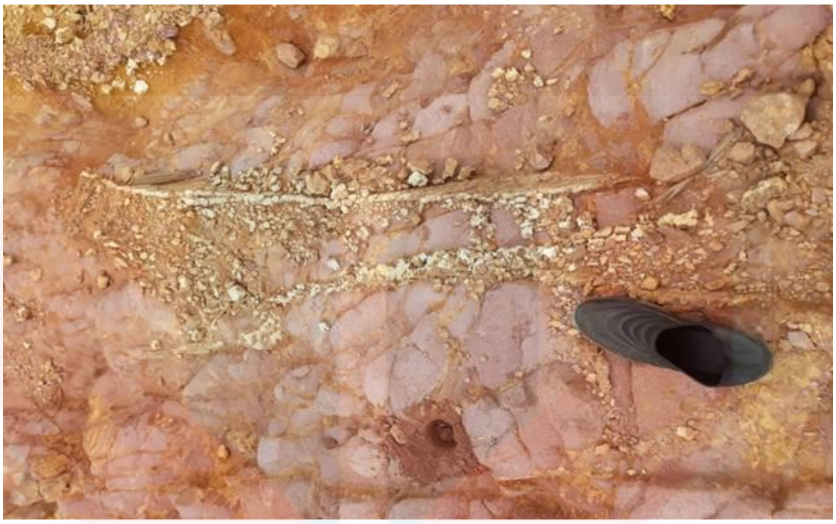


Figure 4.31 shows the quartz vein at waypoint SCS01.

4.4.3 Joint

Joints can be found in the surface of the exposed phyllite, which are mostly extensional joint. Joints data has been collected from wherever they are available in the study area. A simple force direction analysis has been done through the rose diagram as shown in **Figure 4.32** generated from the data collected at way point SCSC1 with coordinates of N 05° 35’ 40.9” E 102° 00’ 35.9” and elevation of 150 metres.

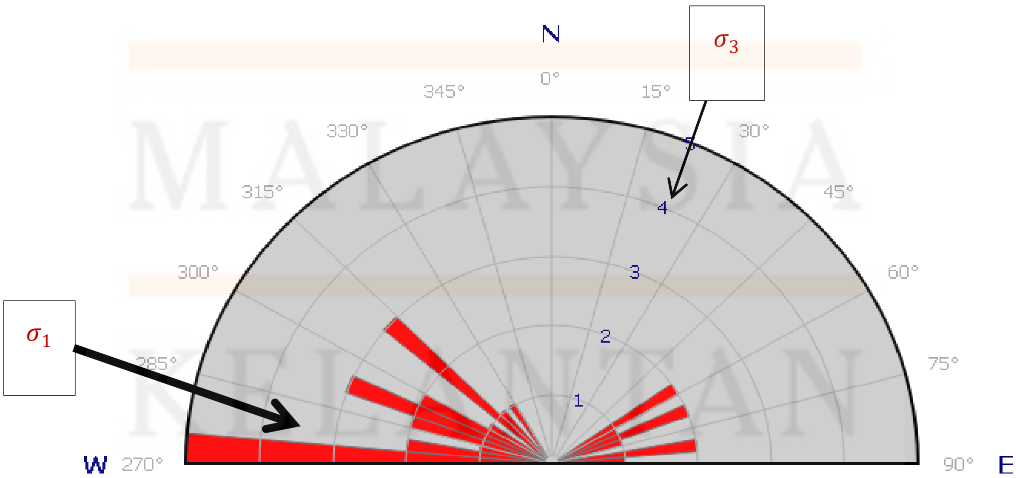


Figure 4.32 shows the rose diagram generated from waypoint SCSC1.

From the rose diagram, the sigma 1 or the maximum principal stress or the greatest stress is approximately from WNW-ESE direction. Since the sigma 3 or the minimum principal stress or the least stress is approximately from NNE- SSW direction. The rose diagram also shows that shear fractures are oriented NE-SW and NW- SE and extensional fractures with an E-W direction.

4.4.4 Fault

Fault is the displacement or sliding of rock blocks on a fault plane because stress applied on the rock blocks. Since no fault had been found during the field observation, lineament analysis has been used to identify the possible fault on the contour map as shown **Figure 4.20**. The lineament was drawn based on the line which separates the different contour patterns. The lineaments are roughly in NNW-SSE direction and WNW- ESE direction.

4.4.5 Fold

Fold is where the rock folded because of stress applied on it under its ductile condition in a deeper region where the pressure cannot be released like the outcrops on the ground. If pressure is released, fault or different grade of fractures as stated previously will be formed. A minor fold was observed in the study area as shown in **Figure 4.33**. This is named as a monocline and not syncline even the strata are folded downwards because the full geometry of a syncline was not observed.

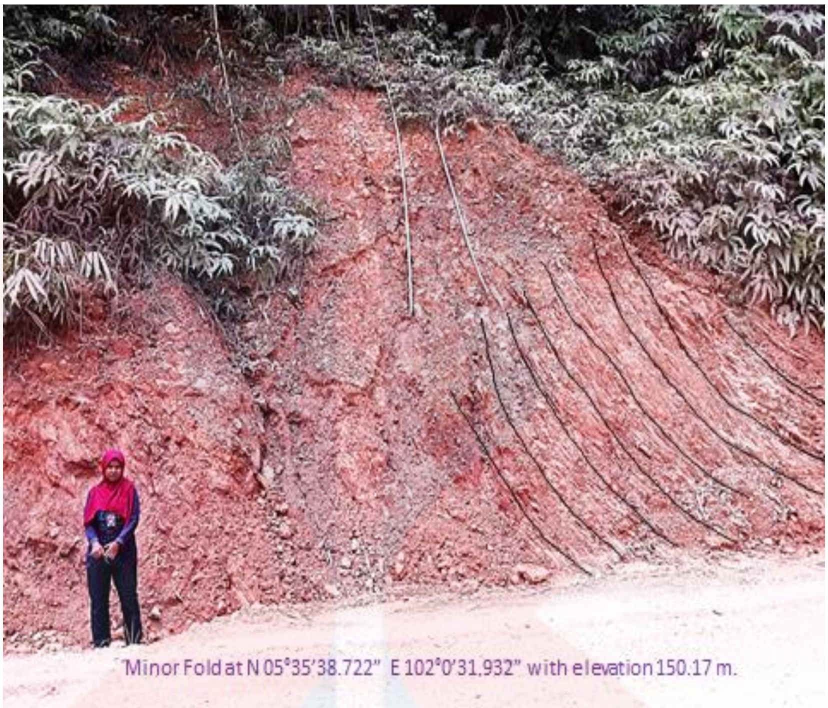


Figure 4.33 shows a minor monoclinal fold at N 05° 35' 8.722" E 102° 0' 31.932" with elevation of 150.17 metres.

4.4.6 Mechanism of structures

Concluding the lineament data and joint data, the maximum principal stress comes from NW- SE direction and the minimum principal stress comes from NE – SW direction. Interpretation has also been made based on the field observation and analysis of other geologic structures folds and cleavage plane. The different mechanisms had been simulated by using Visible Geology.

Strike and dip data from where folds were observed were used to predict any possible folding event that cannot be seen in the study area either buried in the subsurface or due to high vegetation coverage. The probable folding events are shown in **Figure 4.34** and **Figure 4.35**.

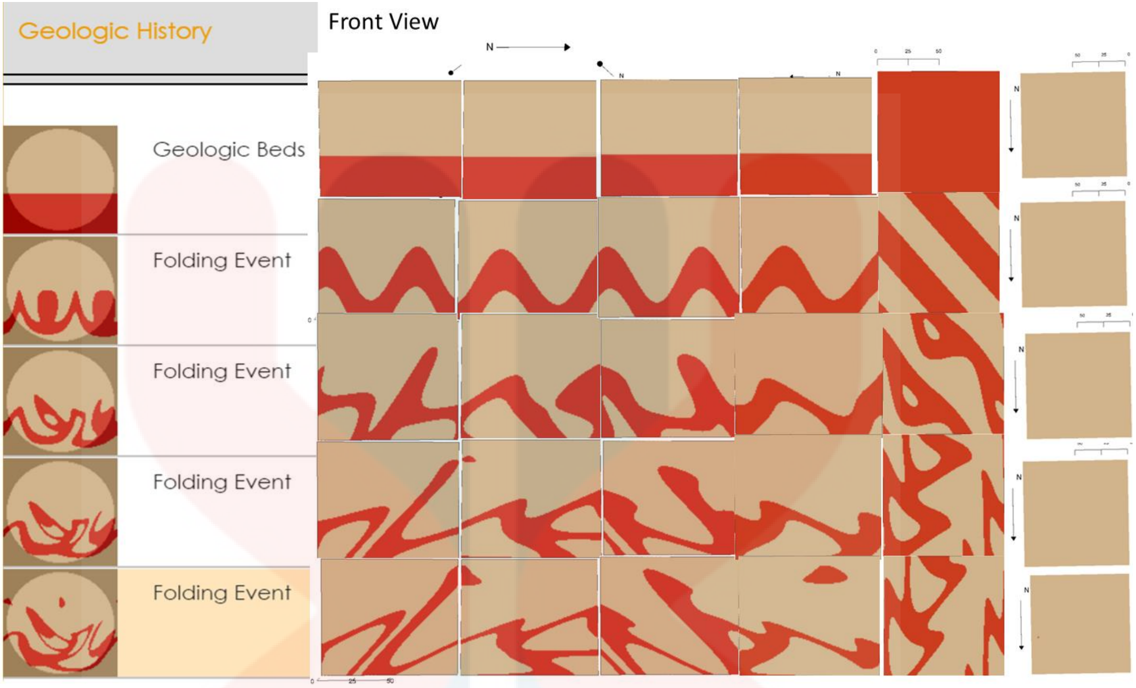


Figure 4.34 illustrates the all the possible folding event that maybe happen in the study area based on the strike and dip data collected from folds. Different views have been shown for each possible event.

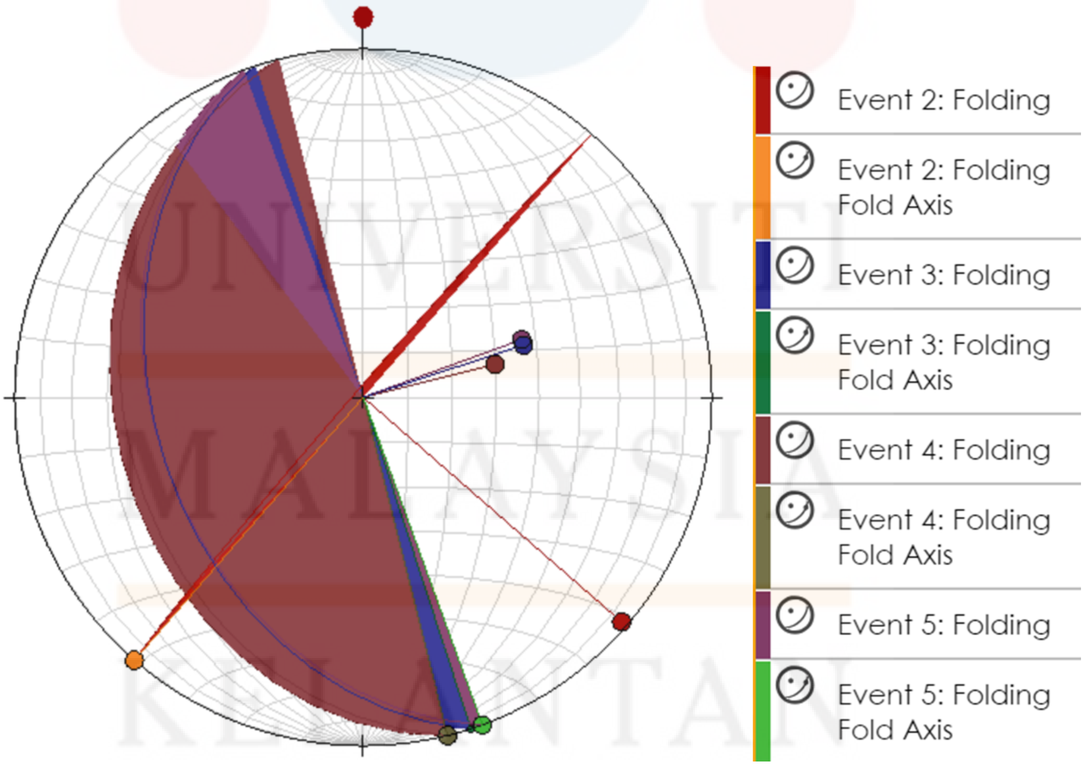


Figure 4.35 shows the stereonet plotted based on the possible folding events in Figure 4.35.

By inputting all the cleavage planes data from the study area, the dipping has been summarized as strike/dip= 165/34, by using contour diagram as shown in **Figure 4.36** and the Visible Geology model as shown in **Figure 4.37**.

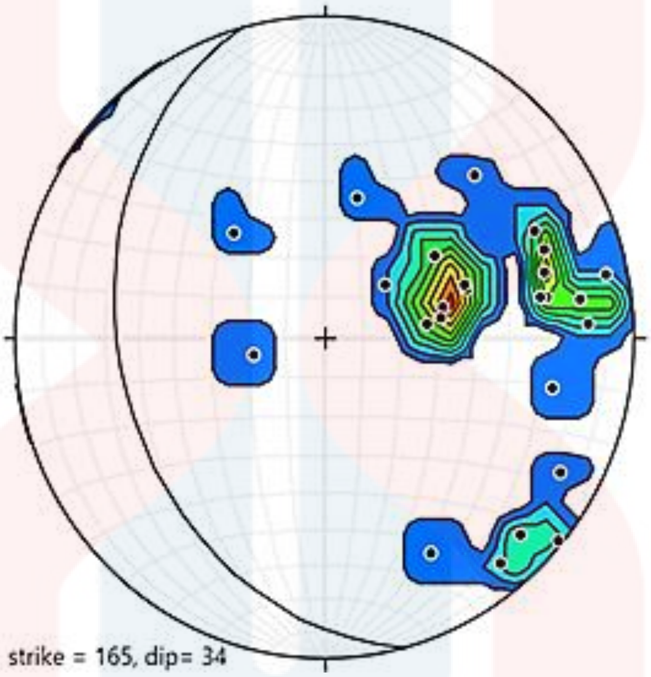


Figure 4.36 shows the contour diagram used to find the average bed dipping in the study area.

Figure 4.37 shows the model of phyllite bed dipping in the study area through visible geology.

4.5 Historical Geology

Sokor before Permian is in shallow marine shelf with occasional volcanic eruption. This can be seen through the tuffaceous phyllite in the study area as shown in **Figure 4.38**. It was then uplifted by the Indosinian Oregeny when the active continental margin of Sibumasu Plate collided with the volcanic Island arc of Indochina Plate during Late Triassic. The bedding shown in mechanism of structures is a result of this collision. During the collision at the convergent boundary, the siltstone and shale after continuous pressure from overlying strata and underwent regional metamorphism which turned them into phyllite by mild pressure and temperature. Phyllite which is shown as argillaceous unit of Telong Formation in the geological map is prevalent in the study area.

The calcareous unit, limestone of Gua Musang Formation were formed at the same period as the argillaceous unit of Telong Formation. The depositional environment of limestone must be high content of calcium carbonate, most probably of seashell from the shallow marine of a tranquil sea. The interbedding between limestone and mudstone as shown in **Figure 4.29** was most probably formed by different turbidity during different level of sea standing. The high sea standing brought high level of mud which formed the mud layer and during the low turbidity because of low sea level, the limestone layer was formed.

The later granitic intrusion has enabled the enrichment of hydrothermal fluid for the gold ore lodes formation (Chen, 2014; Chen, 2013). The quartz veins found in the study area is shown in **Figure 4.39**.

Figure 4.38 shows the tuffaceous phyllite in the study area.

Figure 4.39 shows the quartz veins found in the study area as an evidence of hydrothermal alteration.

CHAPTER 5

BIOGEOCHEMICAL STUDY IN SOKOR

5.1 Introduction

Biogeochemistry is a multidisciplinary field which the chemical relationship between the living things and the geological components or in this particular research, plants, rocks and soils. In this chapter, the biogeochemical study of plant and soil in Sokor are discussed based on the field observation for alteration, characterization and has been related between the rock, soil and plant in the study area.

5.2 Preliminary Study

In the preliminary study, seven sets of soil and plant samples, labelled as 18PCT, 18PCT01, 18PCT2, 18PCT4, 18PCT6, 18PCT9 and PCTBX which have different settings of river, riverbank, off-roadside and slope were collected from the Sokor area as shown in **Figure 5.1** and **Table 5.1**. Soil samples were analysed with Flame-Atomic Absorption Spectrophotometer (AAS) for the elements of silver, Ag; aluminium, Al; iron, Fe; manganese, Mn; and zinc, Zn as shown in **Table 5.2** with absorption peaks in **Table 5.3**. A bar graph has been plotted on **Figure 5.2** for better comparison.

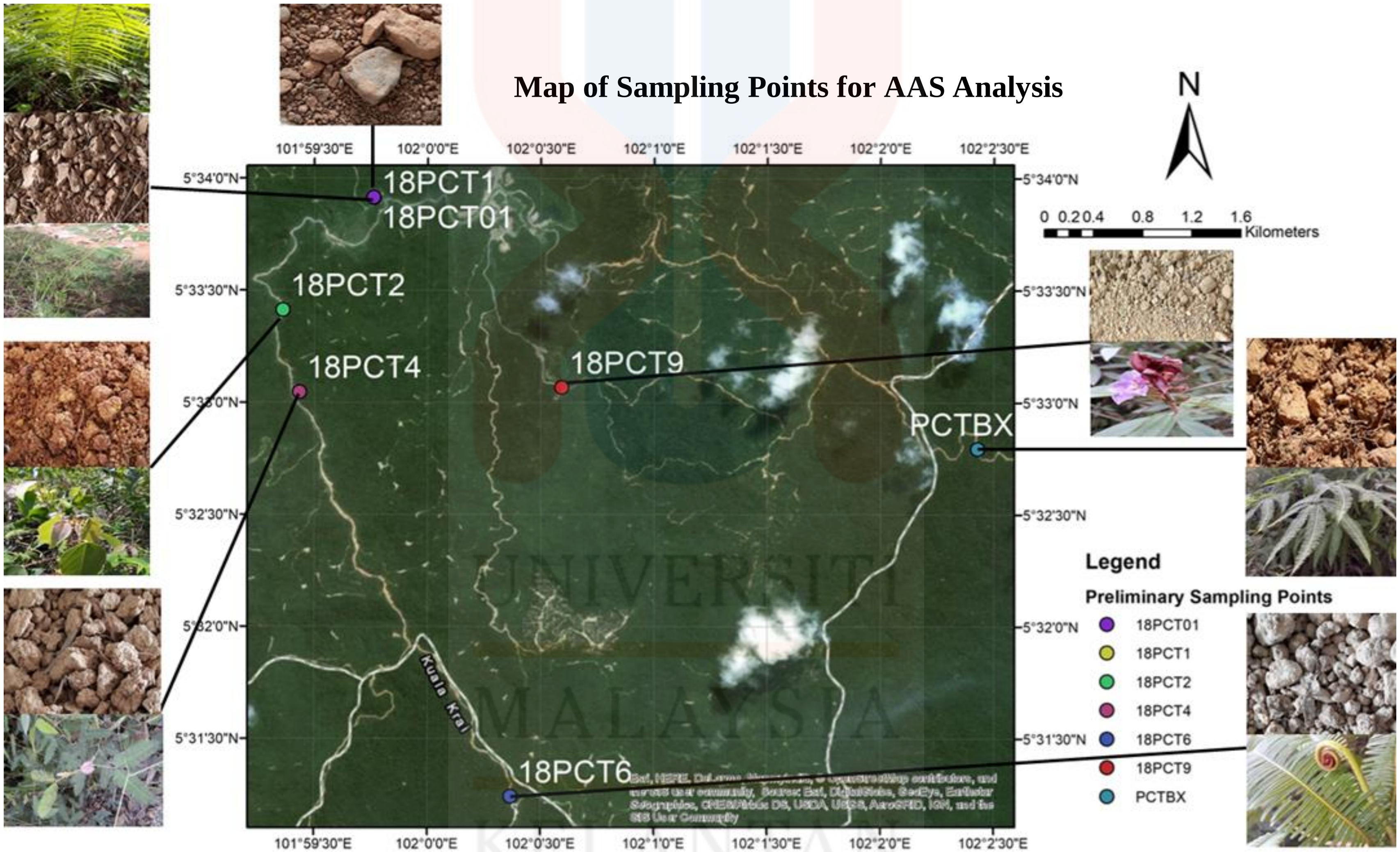


Figure 5.1(a) shows the sampling points for the soil and plant samples for AAS analysis in preliminary study on satellite imagery.

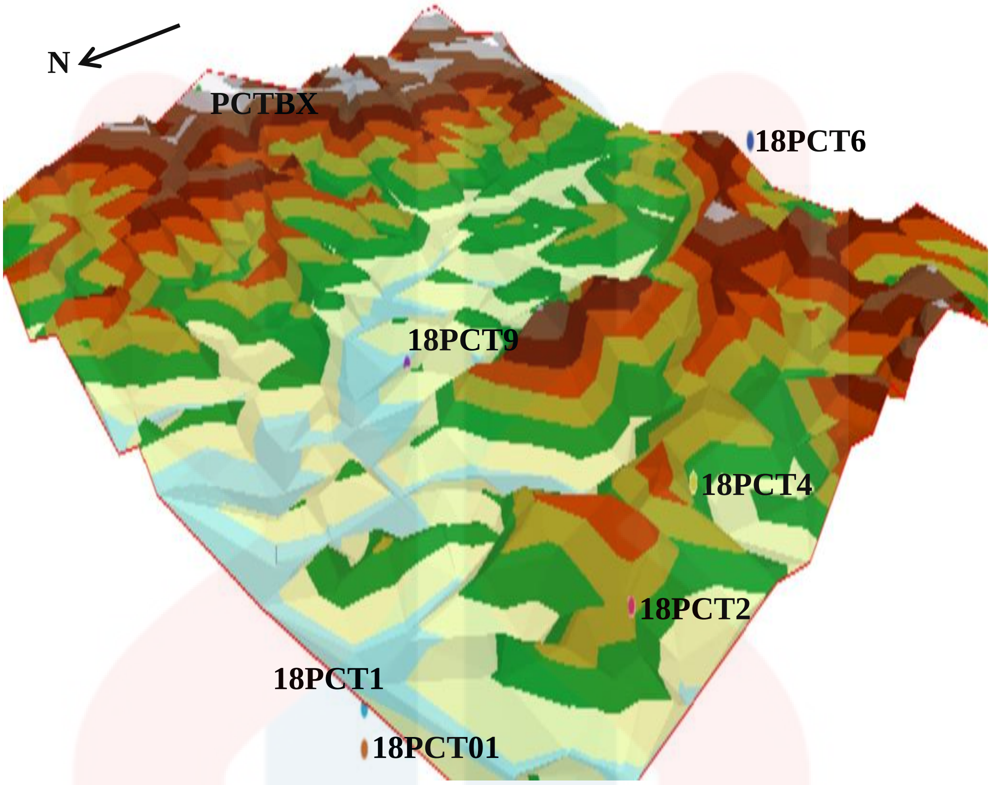


Figure 5.1 (b): 3D Digital Elevation Map of Preliminary Sampling Points. Note that 18PCT01 is river bank of the river 18PCT1 thus is not able to be shown in this map.

Table 5.1: Preliminary Sampling Points.

No	Sampling Point	Setting	Elevation (metres)	Coordinate	
1	18PCT1	River	65.37	05° 33’ 54.8” N	101° 59’ 45.8” E
2	18PCT01	Riverbank	65.63	05° 33’ 54.7” N	101° 59’ 45.9” E
3	18PCT2	Off-Roadside	183.55	05° 33’ 24.8” N	101° 59’ 21.7” E
4	18PCT4	Off-Roadside	225.16	05° 33’ 2.8” N	101° 59’ 26.1” E
5	18PCT6	Off-Roadside	265.59	05° 31’ 14.4” N	102° 00’ 22.8” E
6	18PCT9	River Bank	89.83	05° 33’ 4.0” N	102° 00’ 35.5” E
7	PCTBX	Slope	313.53	05° 32’ 47.66” N	102° 02’ 25.7” E

Table 5.2: Concentration of silver (Ag), aluminium (Al), iron (Fe), manganese (Mn) and zinc (Zn) in preliminary soil samples by using Flame- Atomic Absorption Spectrophotometer (Flame- AAS)

No	Soil Sample	Concentration (ppm)				
		Ag	Al	Fe	Mn	Zn
1	18PCT1	0.019	6.835	14.72	41.28	3.363
2	18PCT01	0.008	8.082	11.03	41.94	6.484
3	18PCT2	0.006	11.60	2.147	0.798	0.200
4	18PCT4	0.005	39.43	11.87	17.22	0.209
5	18PCT6	0.001	18.58	8.259	5.121	0.215
6	18PCT9	0.002	13.30	23.16	37.82	1.228
7	PCTBX	-0.003	24.93	18.79	14.40	0.154

Table 5.3: Absorption Peaks used for Element Analysis in Flame-AAS

No	Element	Absorption Peak (nm)
1	Ag	328.07
2	Al	309.27
3	Fe	248.33
4	Mn	279.48
5	Zn	213.86

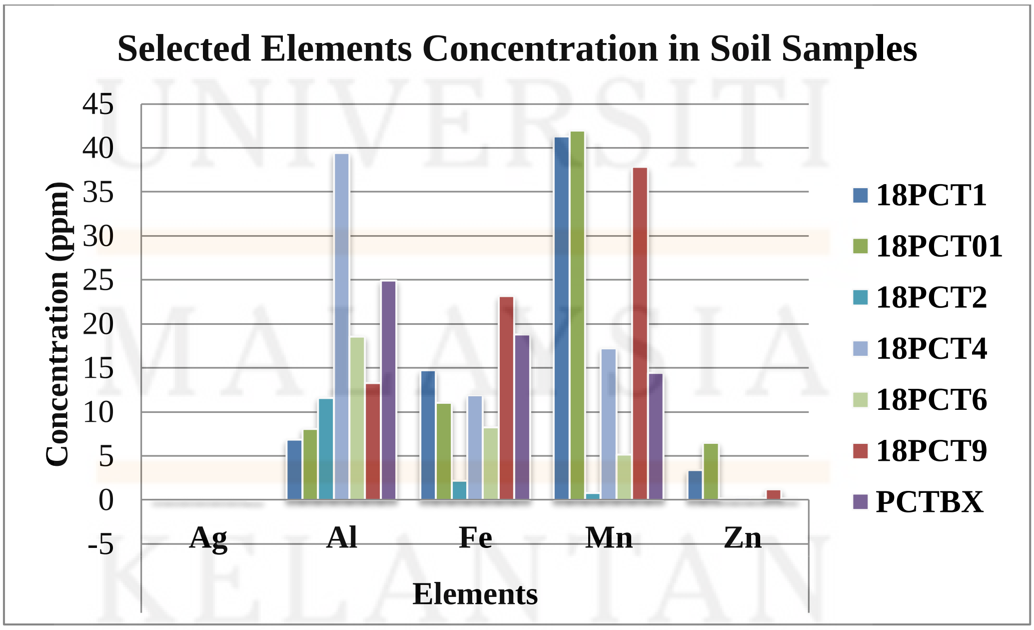


Figure 5.2 shows a bar graph plotted based on the selected elements concentration of soil samples.

As seen in the **Table 5.2** and the graph in **Figure 5.2**, generally different soil sample has different concentration of elements. The silver element, Ag is in a very low concentration in all of the samples collected; it is even below detection limit of the standard solution prepared for slope soil sample PCTBX. The vast difference can be observed between the 18PCT1 and 18PCT01 which were from the same river source which respectively represent the mid-river sediments and the riverbank sediments. It is most probably because of the placer deposit from the running river concentrated the silver in the middle of river and with less silver carried to the bank because of its high specific gravity.

The aluminium Al concentration also varies vastly, highest in roadside 18PCT4 and lowest in the river 18PCT1. This can due to high concentration of aluminium as the constituent element for the chemical compound of clay minerals such as kaolin, smectite and illite in the roadside soil and very small amount of clay minerals in river sediments as they are mostly carried away by the running river away due to relatively lower specific gravity thus less aluminium was deposited in the river sediments.

Iron concentration is highest in riverbank 18PCT9 which most probably has a high amount of iron oxide and iron mineral such as hematite while it is lowest at the roadside 18PCT2 which comparatively has the lowest amount of iron minerals. Manganese concentration is highest in the riverbank 18PCT01while lowest in the roadside 18PCT2 due to the differential deposition of manganese nodules. Zinc is also highest in riverbank 18PCT2 but lowest in slope PCTBX because of more surface runoff carried to the riverbank.

5.3 Sampling Points of Study Area

Four sampling points were selected in the study area as shown in **Figure 5.3** after scoped down from the AAS result analysis. Five soil samples of different colours; and four plant samples of three species where two plant samples are from the same species for comparison, had been collected as shown in **Table 5.4**.

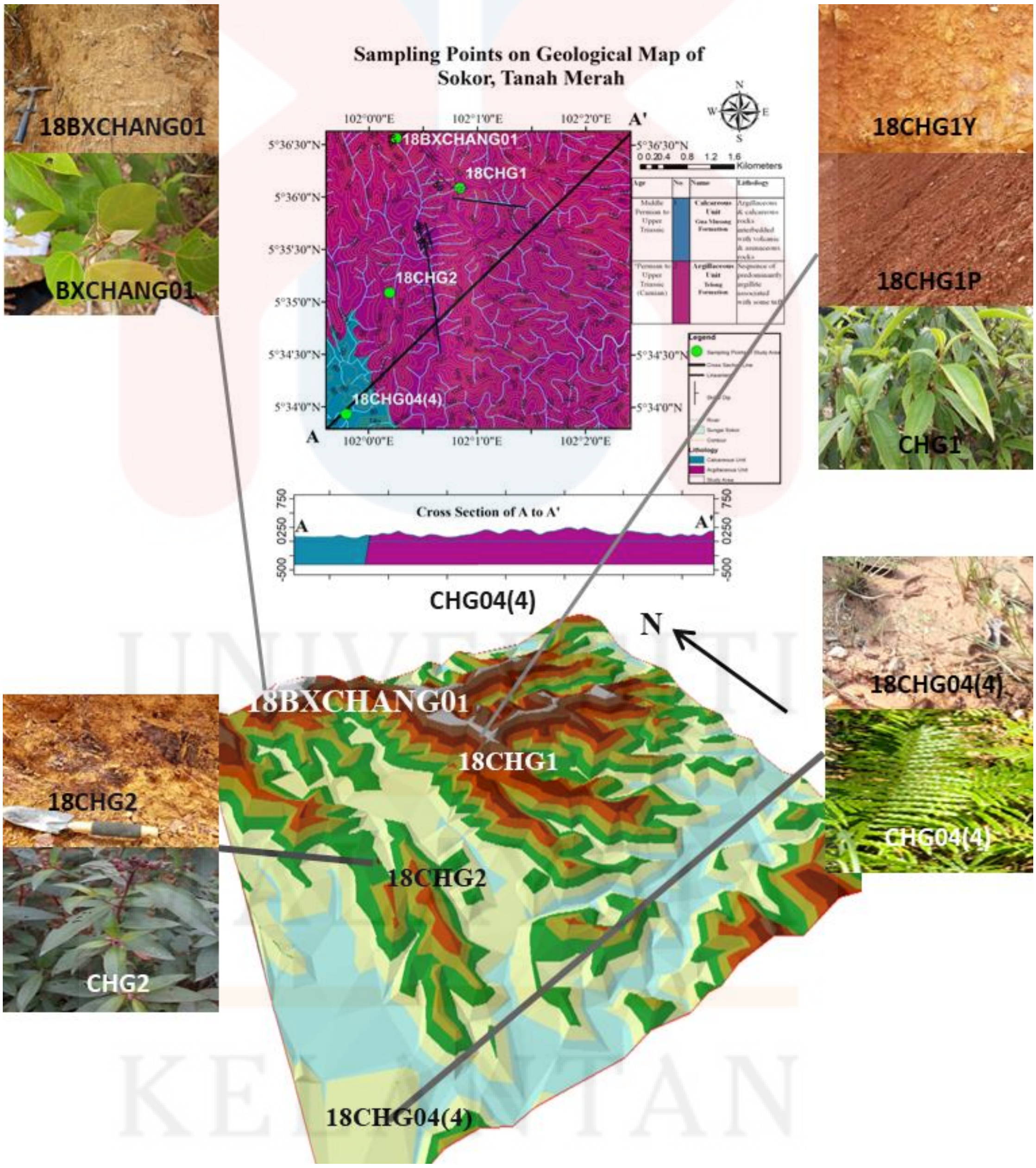


Figure 5.3: Sampling Points on geological map and digital elevation map (DEM).

Table 5.4: Sampling Point of Study Area

No	Sampling Point	Coordinate	Elevation (metres)	Setting
1	18PBXCHANG01	N 05° 36’ 33.8” E 102° 00’ 14.9”	30.1	Off-Roadside
2	18CHG1Y	N 05°36’05.209” E 102°0’50.145”	244.68	Slope
3	18CHG1P	N 05°36’05.311” E 102°0’50.147”	244.66	Slope
4	18CHG2	N 05°35’05.235” E 102°0’11.36”	136.59	Slope Foot
5	18CHG04(4)	N 05°33’55.901” E 101°59’47.57”	78.95	Riverbank

5.4 Fourier-Transform Infrared Spectroscopy Analysis (FTIR)

5.4.1 FTIR on Soil Samples

Through Fourier-transform infrared spectroscopy analysis (FTIR) of soil samples 18BXCHANG01, 18CHG1Y, 18CHG1P, 18CHG2 and 18CHG04(4) in the OMNIC library, data in **Table 5.5** were generated. The best matches are alumina silicate and hydrous alumina silicate which are clay minerals such as kaolin,; bentonite which is the altered volcanic ash; and silicon dioxide which is quartz and hydrous magnesium silicate which is talc, a metamorphic clay mineral from magnesian minerals such as amphibole, pyroxene, serpentinite and olivine through steatization.

Table 5.5: Best Matches of Soil Sample Spectral based on FTIR OMNIC Library. Note that Y=Yes, N=No.

Best Matches	Soil Samples				
	18BXCHANG01	18CHG1Y	18CHG1P	18CHG2	18CHG04(4)
Alumina Silicate	Y	Y	Y	Y	Y
Hydrous Alumina Silicate	Y	Y	Y	N	Y
Hydrous Magnesium Silicate	Y	Y	Y	N	Y
Amorphous Hydrophobic Silicon Dioxide	Y	N	N	N	Y
Kaolin	N	N	Y	Y	N
Bentonite	Y	Y	Y	Y	Y
Crystalline free-Silicon dioxide	Y	N	N	N	N

5.4.2 FTIR on Plant Samples

Table 5.6 shows the functional group found in the plant samples BXCHANG01, CHG1, CHG2 and CHG04(4) through FTIR are inorganic phosphate, aliphatic primary amines, aliphatic hydrocarbons, primary aliphatic alcohols, aliphatic tertiary amides and aliphatic carboxylic acids.

Table 5.6: Functional Group found in Plant Samples through FTIR. Note that Y=Yes and N=No.

Functional Group	Plant Sample			
	BXCHANG01	CHG1	CHG2	CHG04(4)
Inorganic Phosphate	Y	Y	Y	Y
Aliphatic Primary Amines	Y	N	N	Y
Aliphatic Hydrocarbons	Y	Y	Y	Y
Primary Aliphatic Alcholos	Y	Y	N	N
Aliphatic Tertiary Amides	N	Y	N	N
Aliphatic Carboxylic Acids	N	Y	N	N

5.5 X-Ray Diffraction Analysis (XRD)

Based on the X-Ray Diffraction analysis (XRD) in **Figure 5.4**, quartz (SiO2) has been found at the highest amount or peaks at 2Theta= 26.624 in all five soil samples analysed. Silica due to its atomic arrangement is resistant towards physical and chemical weathering thus can retain in the soil in a large amount. Cristobalite, a silica (SiO_2) polymorph found in silica rich volcanic ash and sedimentary environment has also found in a small amount as the evidence of pedogenesis from volcanic ash deposited during volcanic eruption million years ago.

Other minerals found are clay minerals halloysite, kaolinite, nacrite, dickite and pyrohyllite, aluminium hydroxide—gibbsite and iron minerals—hematite and goethite. Exception is in 18CHG1P where metahalloysite instead of halloysite was found and pyrohyllite was not found. Moganite, a type of silica and magnetite, an iron mineral were found in 18CHG04(4).

The composition of each mineral found in each soil sample had been pie-charted in **Figure 5.5** while the elemental composition had also been calculated based on the mineral weightage and tabulated in **Table 5.7**. Note that the XRD analysis does not represent all the mineral composition of the soil sample, thus the data only able to show the found minerals and elemental data were derived from the found minerals.

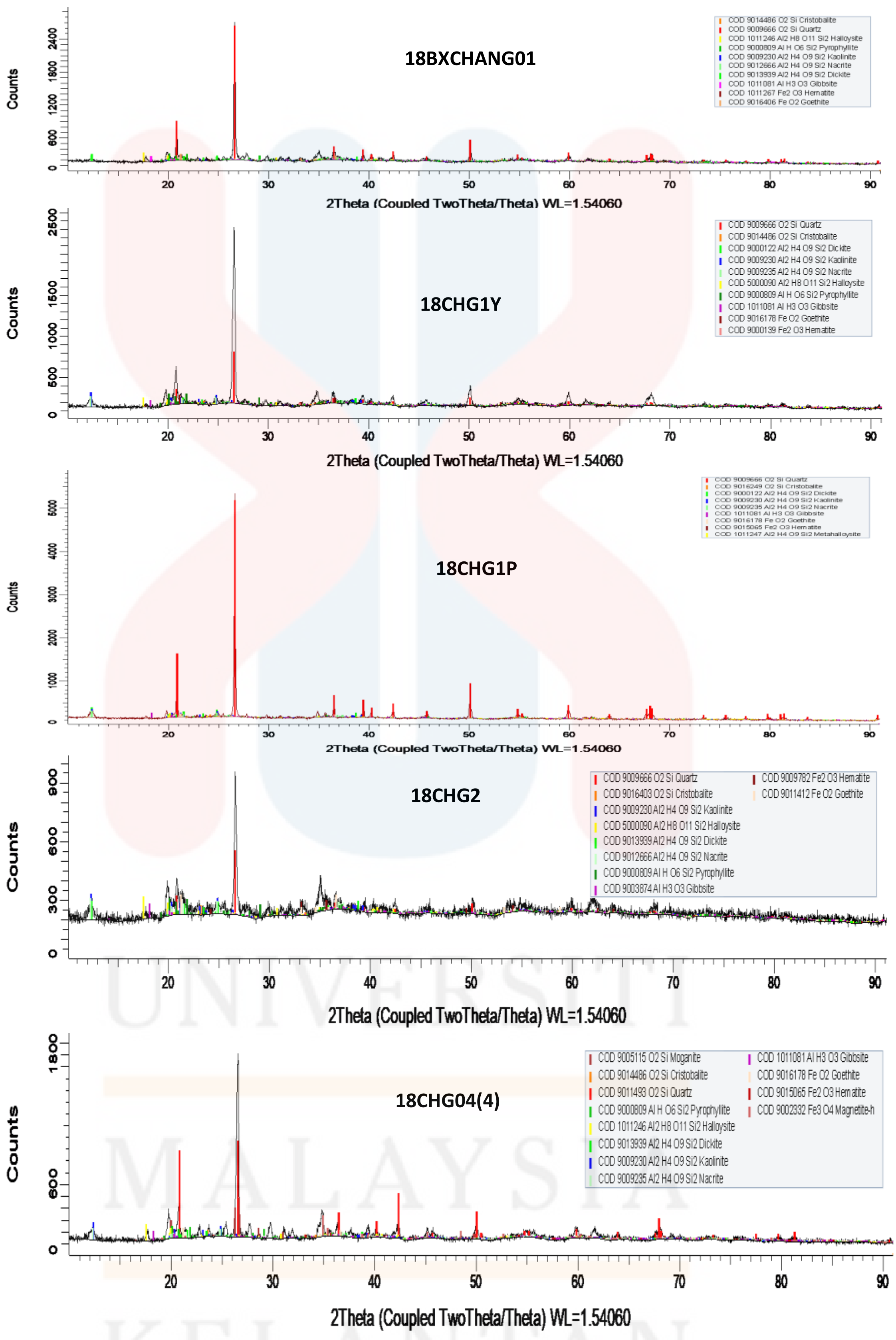


Figure 5.4: XRD results of soil samples 18BXCHANG01, 18CHG1Y, 18CHG1P, 18CHG2 and 18CHG04(4).

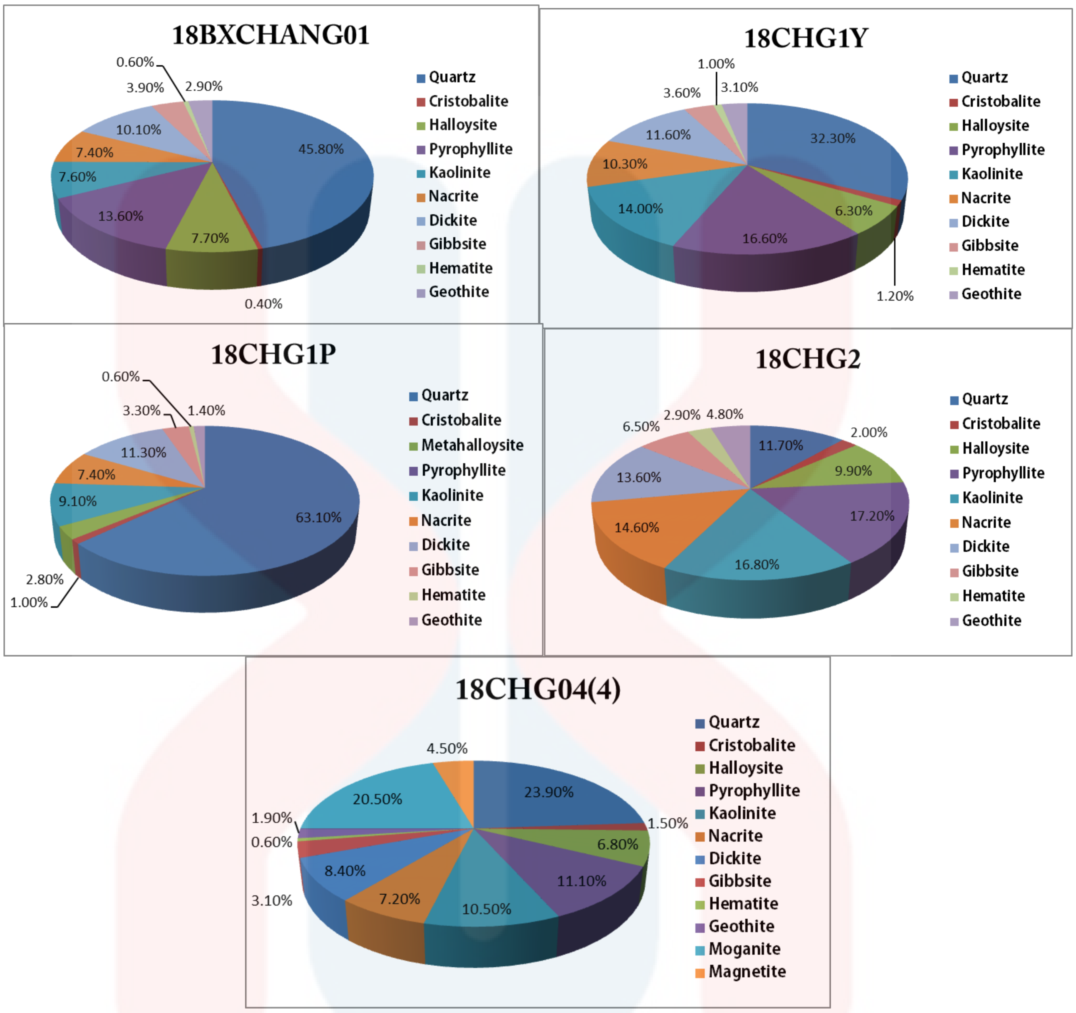


Figure 5.5: Mineral Composition Pie Chart of Soil Samples 18BXCHANG01, 18CHG1Y, 18CHG1P, 18CHG2 and 18CHG04(4)

Table 5.7: Elemental Composition based on XRD results

Soil Sample	Elemental Percentage (%)				
	Hydrogen	Oxygen	Aluminium	Silicon	Iron
18BXCHANG01	0.8	54.1	10.0	32.8	2.3
18CHG1Y	1.2	54.3	15.2	26.0	3.3
18CHG1P	0.6	53.9	7.5	36.6	1.3
18CHG2	1.3	54.1	16.1	23.4	5.1
18CHG04(4)	0.8	53.0	9.4	31.9	4.9

5.6 X-Ray Fluorescence Analysis (XRF)

Silicon dioxide or quartz is always the main composition in soil as shown XRF result in **Table 5.8**. Iron and potassium oxide were also found in every soil sample. Titanium, barium, nickel, chromium, vanadium and manganese oxides were also found in soil samples in varying composition thus were only detectable in certain samples with a generally low percentage.

Table 5.8: XRF Results of Soil Samples

Analyte	Analyte Percentage in Soil Sample (%)				
	18BXCHANG01	18CHG1Y	18CHG1P	18CHG2	18CHG04(4)
SiO2	58.3714	65.0590	75.2680	47.8877	56.0723
Fe2O3	26.5126	25.9119	18.9846	44.4303	28.2000
K2O	6.8570	6.9491	3.5512	5.8288	10.2168
TiO2	7.6795	0.9145	-	1.7559	-
BaO	-	0.5982	1.6224	-	4.9183
NiO	-	0.4033	0.4054	-	0.2044
Cr2O3	-	0.1639	0.1684	-	-
V2O5	0.4178	-	-	0.0973	0.3883
MnO	0.1618	-	-	-	-

5.7 Inductively Coupled Plasma Mass Spectrometry Analysis (ICPMS)

Only plant samples had been characterized under ICPMS and the total metal content in ppm had been tabulated in **Table 5.9**. Gold is not traceable in all of the plant samples and silver was also detected to be very low in all the plant samples.

Table 5.9: ICPMS Results of Plant Samples.

Element	Total Metal Content in Plant Sample (ppm)				
	BXCHANG01	CHG1	CHG2	CHG04(4)	
				BI	DL
Mn55	63.80	30.95	19.57	2.68	48.90
Fe57	66.14	14.82	223.09	157.78	44.31
Zn66	0.46	BDL	0.77	0.14	68.86
As75	0.07	0.01	0.19	0.23	0.05
Pb208	0.10	0.02	0.23	0.32	0.24
Pb206	0.17	0.04	0.40	0.54	0.42
Ag107	6.75e-3	1.47e-3	1.10e-1	2.24e-2	BDL
Cu65	0.17	0.19	0.27	0.22	1.99
Al27	44.62	62.10	95.50	94.16	42.71

According to AAS specific for gold, the gold concentration in soil sample 18CHG1Y is less than 0.001 ppm.

5.8 Sample Observations

5.8.1 Rock Sample Observation

The rock sample in sampling points 18BXCHANG01, 18CHG1 and 18CHG2 were identified as phyllite except rock in 18CHG04(4) was identified as metamorphosed limestone inter-bedded with metamorphosed mudstone or phyllite. Most phyllite samples collected were highly weathered thus the thin section were not able to be seen clearly thus the samples had been viewed under stereoscope and discussed in Chapter 4.

Quartz veins collected are shown as an evidence of hydrothermal alteration and part of ore path finding manifestation. Quartz vein are abundant in sampling point 18CHG1 with coordinate of N 05°36’05.209” E 102°0’50.145” with elevation of 244.68m and some have shown alteration on the surface or within the quartz veins as shown in **Figure 5.6**. The minerals are younger than the quartz veins and most probably formed by development in the fissures of quartz vein or encrustation by ferromagnesian mineral grains.

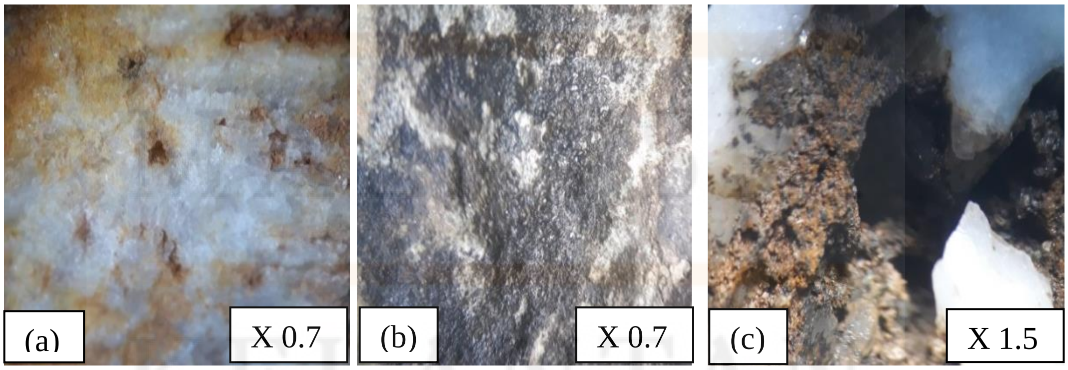


Figure 5.6: Hydrothermal Alteration brought on or in quartz veins: (a) weathered included metal minerals shown in brown colour; ferromagnesian or mafic minerals (b) on quartz vein surface and (c) developed with the quartz veins as shown in brown to black colour.

5.8.2 Soil Sample Observations

As shown in **Figure 5.3** in section 5.2, the soil samples collected were of different colour. Soil sample 18BXCHANG01 was in light brown colour, 18CHG1Y in brownish yellow, 18CHG1P is in reddish brown 18CHG2 in yellowish brown, and 18CHG04(4) in greyish yellow.

5.8.2 Plant Sample Observation

Plant sample BXCHANG01 is a dicotyledonous plant with pinnate primary veined scalariform secondary veined and tertiary veined, ovate to lanceolate shaped entire leaves with acuminate apexes and spiral leaf arrangement. The leaves are hairy during fresh and not shiny after drying. The barks are fibrous and aromatic. The root is tapped with extensions. Its other plant morphology has been shown in **Figure 5.7**.

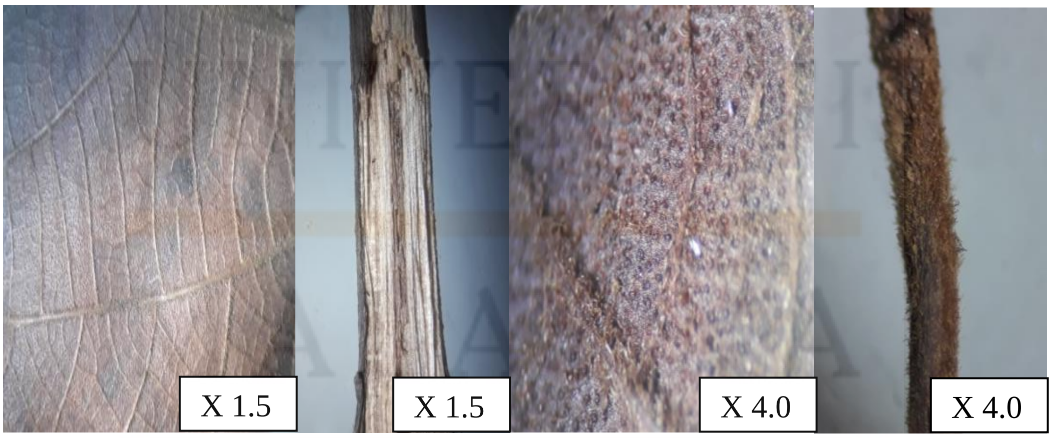


Figure 5.7: BXCHANG01: Leaf veins, Stomata, Vascular system and root hair from left to right

CHG1 and CHG2 are *Melastoma malabathricum* which can be easily identified though the striking characteristics of its purple flowers and buds and leaves of lanceolate shape, primary triverved and secondary parallel veins and therir hairy surface. The plant morphology is shown in **Figure 5.8**.

Figure 5.8: *Melastoma malabathricum*: Leaf vein, Flowers and Vascular System from left to right.

CHG04(4) is *Blenchum indicum* or water fern or swamp fern in its general name. This can be identified through the simple vascular system, parallel veined compund leaves with spores on the back of leaves as gametophyte for reproduction as shown in **Figure 5.9**.

Figure 5.9: CHG04(4) *Blechnum indicum*: Leaf vein, Vascular System and spores on the back of compound leaves from left to right.

5.9 Relationship between Geochemistry and Mineralogy with Plant using Plant and Soil in Ulu Sokor.

5.9.1 Soil and Alteration Mineralogy and Geochemistry

From XRD, XRF and FTIR results, the main composition of soil samples are clay minerals. The soil samples collected are strongly leached clay accumulated soil, ultisol and intensive weathered oxisol. In general sense, red coloured soil has a high content of iron but in 18CHG1P which is the most reddish soil among all soil samples analysed surprisingly has the lowest iron content as shown in XRD and XRF results. This can be explained that red soil is from well drainage zone where the readiness to be oxidized is higher than other soil and is more susceptible to leaching. Yellow to yellowish brown soils as in 18BXCHANG01, 18CHG1Y, 18CHG2 and 18CHG04(4) are more compacted and have more hydrated iron minerals thus no rusty colour is formed. The greyish colour in 18CHG04(4) shows it is a very poor drainage soils where this anaerobic condition has favoured the reaction between manganese and iron minerals.

Clay minerals from the soil sample can be used to predict the parent materials which are plagioclases and feldspars through hydrothermal alteration that has been observed throughout Sokor area. Two types of alteration have been observed: argillic and phyllic alteration which are of different temperature. The prevalent argillic alteration is producing the kaolinite and dickite to replace plagioclase and amphibole at low temperature while the pyrophyllite which form under temperature higher than 300°C are also present. Quartz deposition is also common in the study area. This kind of hydrothermal alteration can have ore deposit named as supergene enrichment through weathering by circulation of meteoric water percolates primary sulphide ore minerals and redistribute the minerals through reaction between leaching minerals and the primary minerals thus accumulate below the water table in an enrichment zone which is at the base of the oxidized portion of an ore deposit.

Pyrite has been found near to the study area where it has been found together with quartz and sericite, a typical phyllic alteration assemblage. Phyllic alteration occurs through hydrogen-ion metasomatism in permeable rock by hydrothermal fluid circulation. Through this high temperature acidic condition, plagioclase is altered to sericite while mafic minerals are altered into quartz. These hydrothermal fluid activities in Sokor had also been studied by a team of China geologist leaded by Li Bin, 2010. Structures which are similar to thin selvages had also been found in the study area indicating a highly altered area of deep environment where the outer mafic minerals replaced by chlorite while plagioclase by sericite as shown in **Figure 5.10**.

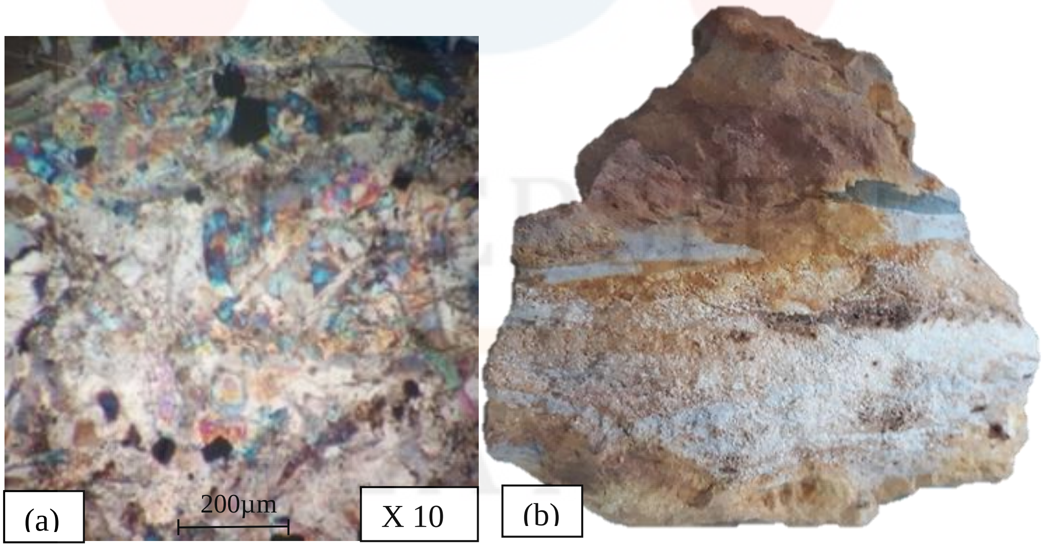


Figure 5.10: Phyllic Alteration: (a) Pyrites as opaque minerals in thin section under XPL; (b)Thin selvages appear in grey and white colour on a rock sample collected which is harder than the surrounding rock may indicate a phyllic alteration in deep environment.

5.9.2 Geochemical Anomaly

Based on the different elemental concentration of soils in preliminary study, geochemical anomaly can be seen on each element distribution map produced: silver (Ag), aluminium (Al), iron (Fe), manganese (Mg) and zinc (Zn) are respectively shown in **Figure 5.11**, **Figure 5.12**, **Figure 5.13**, **Figure 5.14** and **Figure 5.15**. In all of the element distribution maps, the red colour indicates the lowest concentration presented in soil through AAS analysis., while the dark blue colours indicates the highest concentration among all the collected data. With that, the contour coloration shows the regions where certain elements are or were concentrated in and where the elements are or were less or known as geochemical anomaly.

River bank and river sediments from 18PCT9 followed by 18PCT1 and 18PCT01 and, through overlaying through interpolation and equal weightage in **Figure 5.16**, show the highest probability of gaining ore among all the sampling points. Main erosion and transportation by the running water of the perennial river, Sungai Sokor have contributed to the placer deposit of heavy metals with high specific gravity. The lenses of massive polymetallic sulphide have also been recorded in the river 18PCT1 along the contacts of limestone and phyllite (Hutchinson, 1986). Thus these areas are more prospective.

Relationship of elevation and each element concentration has also been scatter-plotted with best regression squared line in **Figure 5.17**. Most elements show inverse proportional relation with the elevation, which means the lower the elevation, the higher the element concentration except aluminium which is more abundant in higher elevation while iron concentration are more fluctuated. Thus, geomorphology and elements distribution are relatable.

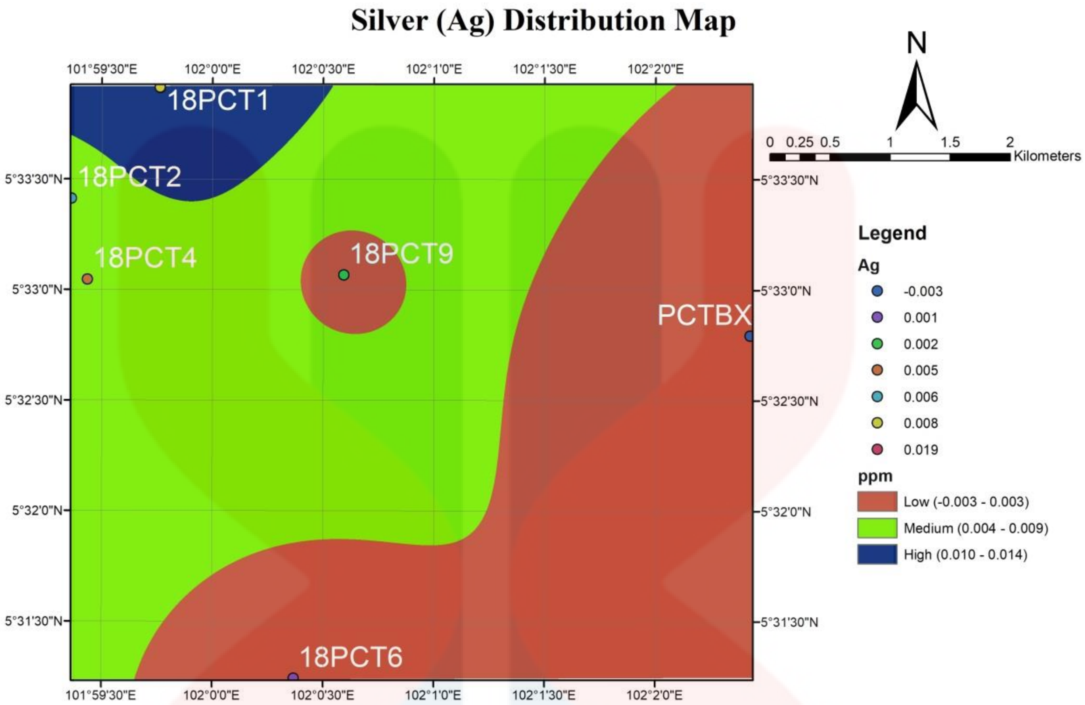


Figure 5.11: Silver (Ag) Distribution Map.

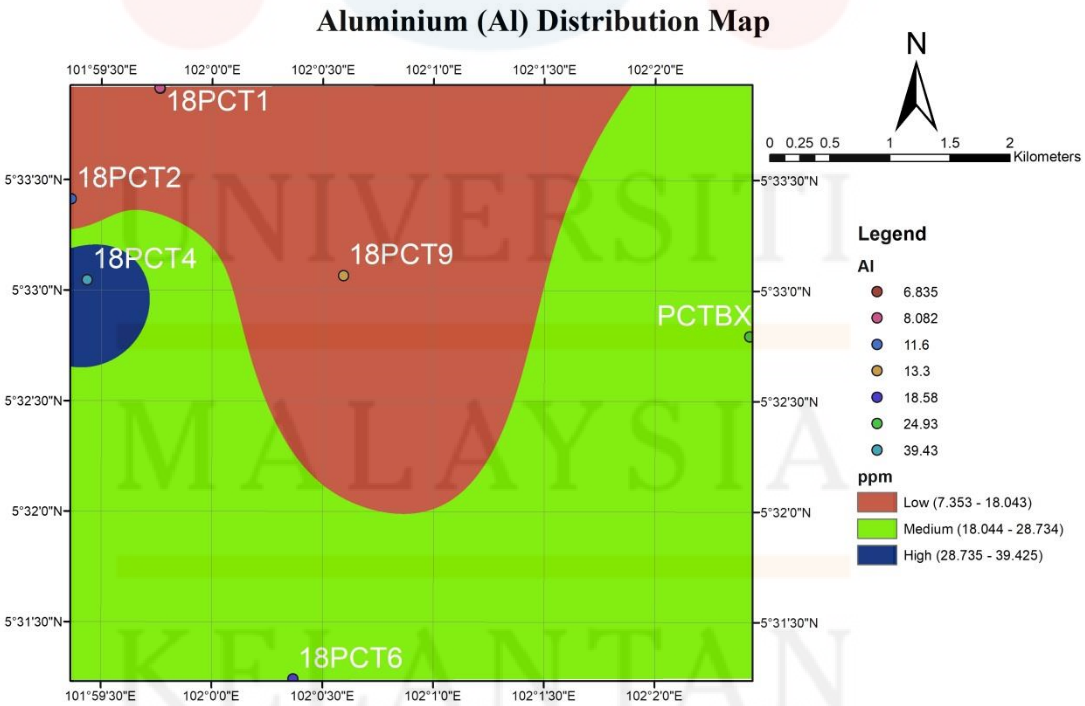


Figure 5.12: Aluminium (Al) Distribution Map.

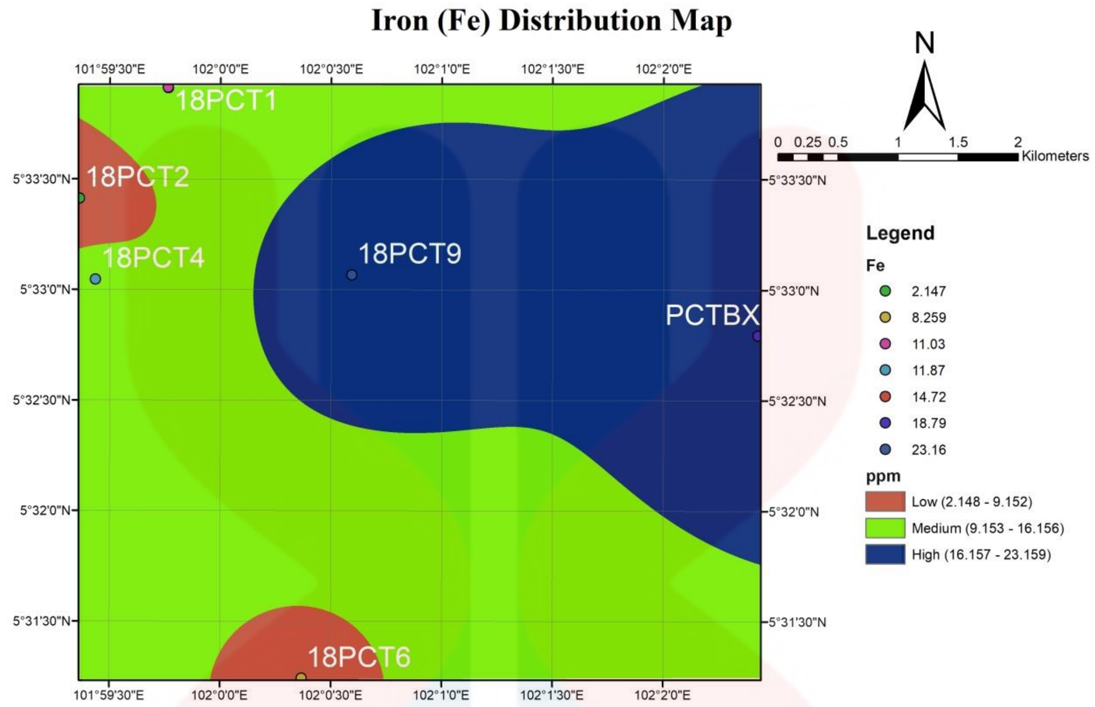


Figure 5.13: Iron (Fe) Distribution Map.

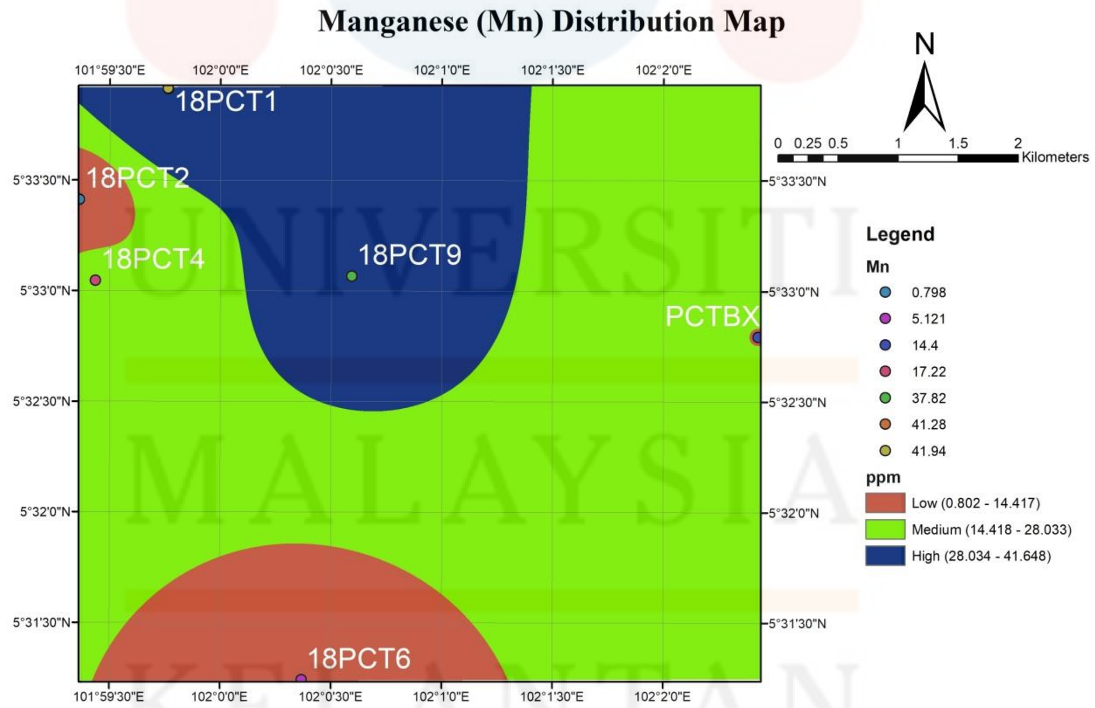


Figure 5.14: Manganese (Mn) Distribution Map.

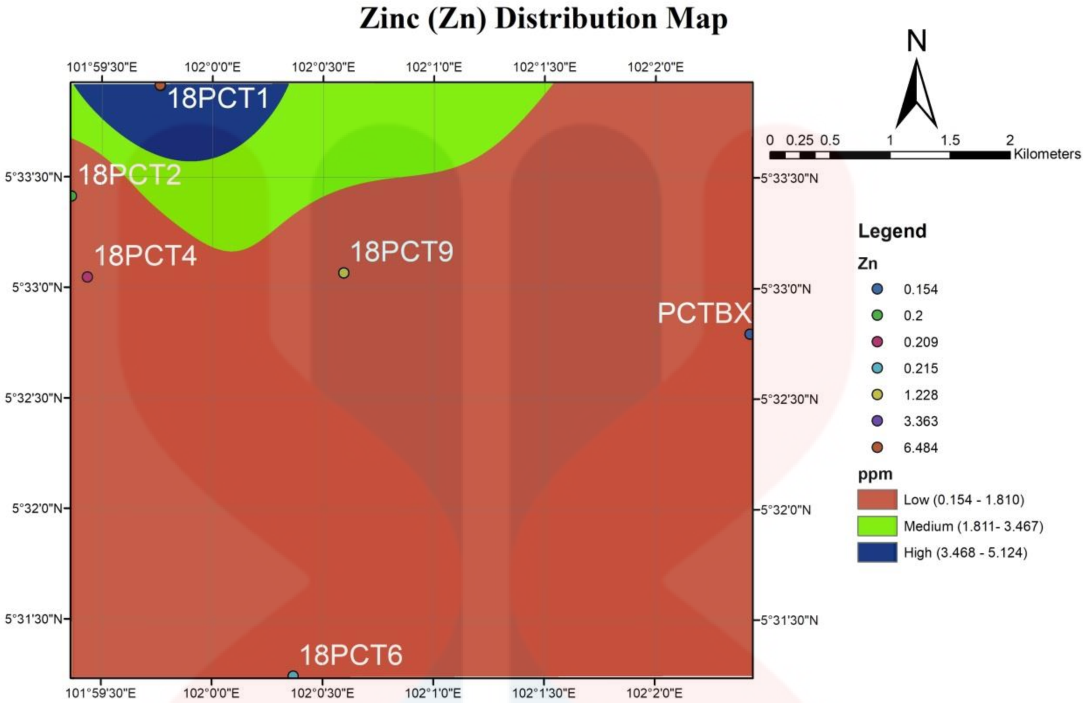


Figure 5.15: Zinc (Zn) Distribution Map.

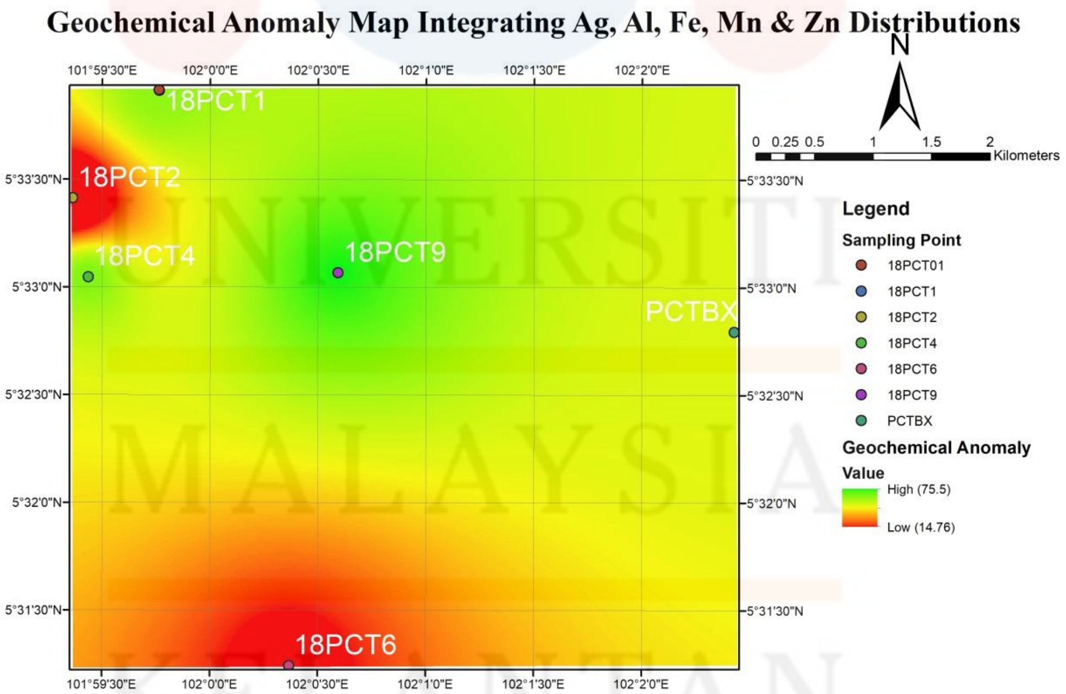


Figure 5.16: Geochemical Anomaly Map which sums up anomaly of elements Silver, Aluminium, Iron, Manganese and Zinc.

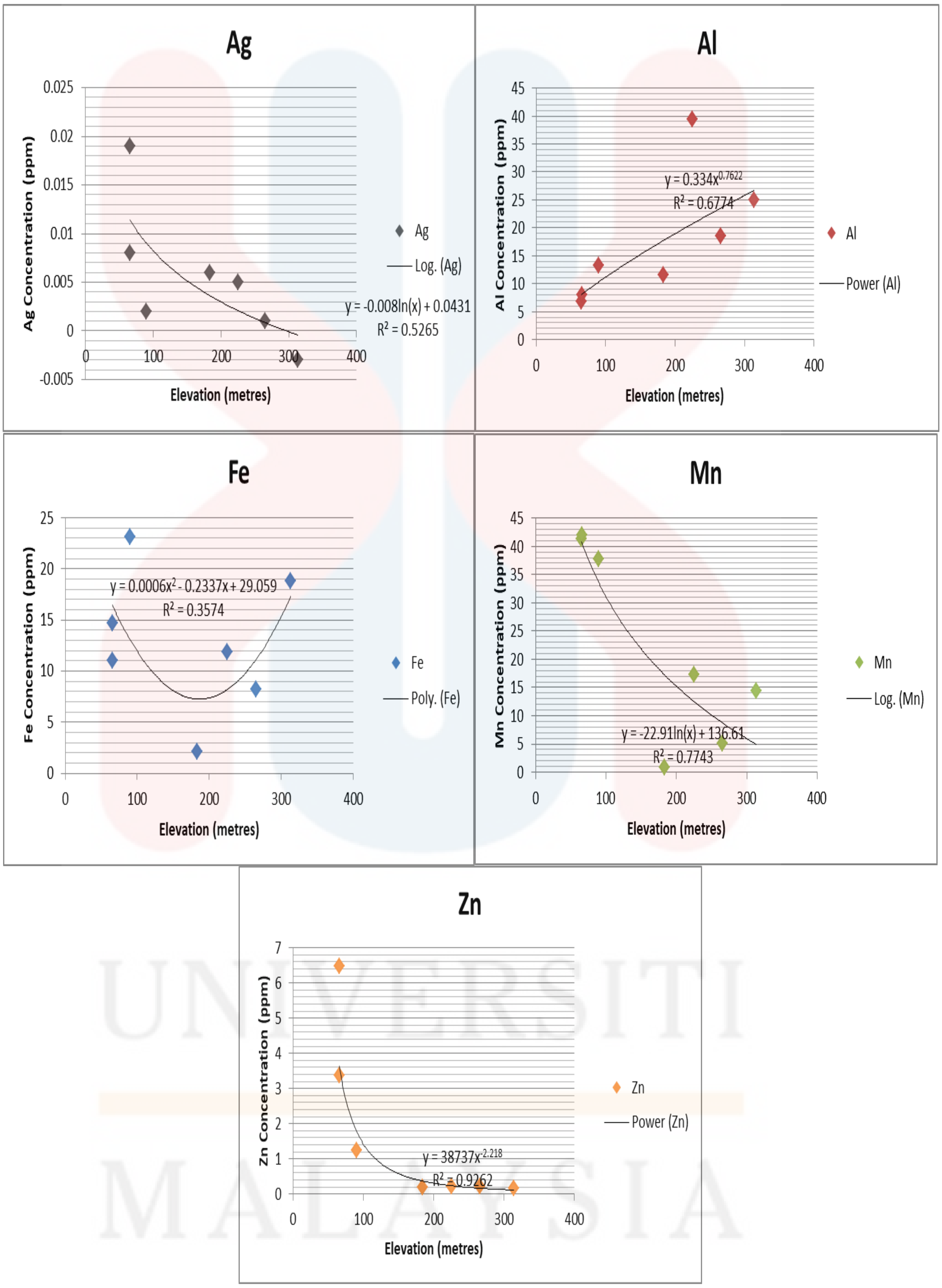


Figure 5. 17: The relationship between elevation and metal concentration

5.9.3 Relationship of Plant Morphology and Element Concentration

CHG2 *Melastoma malabathricum* has shown the highest iron and silver found in ICPMS, which can be correlated with the highest iron found in soil sample 18CHG2 through XRF and XRD. Thus, the best hyperaccumulation has shown in sampling point 18CHG2. In the other end, CHG1 *Melastoma malabathricum* has the lowest iron and silver content as soil sample 18CHG1P has the lowest iron found thus the iron accumulation is the lowest in this plant. Since the same species has been employed in both sampling point, it can be deduced that the accumulation of metal in plant is dependent on the source of absorption which is the soil. Morphologically, CHG2 was with striking purple flowers and buds, the leaves also have higher green colour intensity than those of CHG1 which is without any flowers found as seen in **Figure 5.3**. Thus, the flower and leaf colour may indicate the iron content of the particular plant thus the soil where the elements are absorbed.

5.9.4 Non –absorptablity of Elements by Plant

Silver in CHG04(4) *Dicranopteris linearis* and gold in all plant samples was not traceable analysed under ICPMS. At 18CHG04(4), two different fern species of similar height were collected: *Blenchum indicum* and *Dicranopteris linearis* at the same time and same locality but they show a different absorption ability on the same elements. *Blenchum indicum* has a better absorption on iron, arsenic, lead-208, lead-206, silver and aluminium while *Dicranopteris linearis* has a better absorption on manganese, zinc and copper. These may due to the different enzyme persent in different fern species thus having different nutrient requirements. Sign of phtotoxification has not been observed.

No gold was detectable under ICPMS. In term of plant physiology the gold maybe too little to be absorbed by the smal plants collected or even too fast to be disposed through leave falling while larger plant has a longer bioaccumulation thus will have more detectable element concentration. This can be explained based on the soil samples as no gold or too little amount has been found in the soil. It may due to the distances between the gold ore and the plant root system are too far where the root cannot reach the gold as shown in schematic diagram **Figure 5.18**. It can also indicate there is no gold placer deposit in the sampling points or the gold has been transported to a lower elevation by erosion. Or the simplest explanation would be no gold is found in the study area. This made no concrete relationship can be drawn between gold, silver or any untraceable element with plant in this research as a larger plant may has bioaccumulated the which has not been collected.

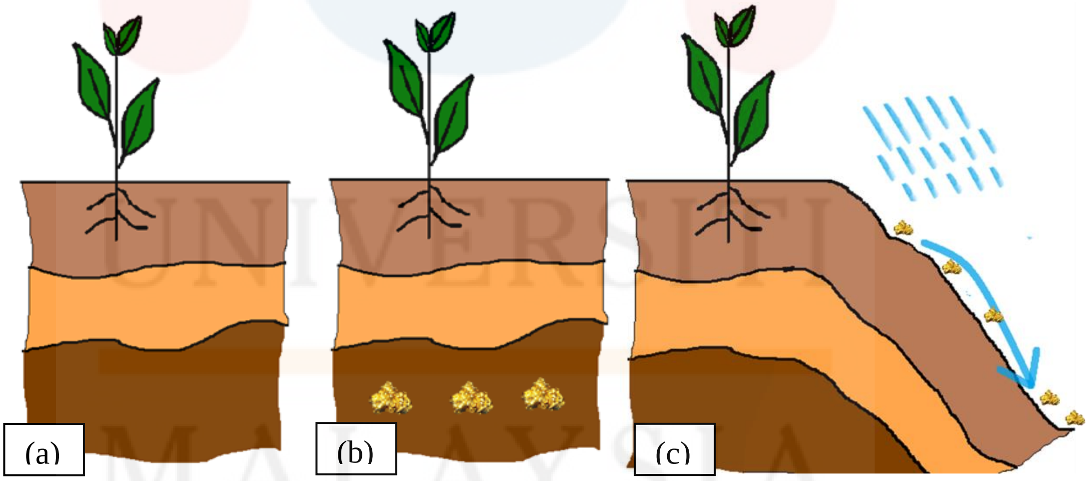


Figure 5.18: Schematic Diagram which shows possible geographical reason for particular metal that is not absorbed by plant: (a) there is no such metal in the setting; (b) the ore is seated too far from where the roots absorb nutrient from; (c) the original seated minerals have been eroded.

CHAPTER 6

CONCLUSIONS AND SUGGESTIONS

6.1 Conclusions

All objectives have been achieved but not with full, firm and concrete validity. This is due to the natural setting of the study area and the cost, time and safety restriction. A geological map of study area with 25 kilometres square has been successfully produced with a broader spectrum of rock designation of argillaceous and calcareous units. The historical geology has been concluded to be series of sedimentation, plate tectonic collision and hydrothermal alteration brought by magma intrusion through field observations and interpretation on geological structures mechanisms which shape the current bed dipping of Sokor, Kelantan.

Argillic and phyllic alteration have been found in Sokor area indicating possible more ore deposits in Sokor, Kelantan. Iron and silver have shown a positive relationship between the plant and the soil iron content. Thus it can be concluded that plant can be a potential ore finder. Since there is no traceable gold was found in the study area, a braver prediction of relationship between the precious element, gold and plant cannot be drawn directly in this research.

The application of various characterizations is important to confirm the occurrence of certain elements or minerals as different machines have different limits and calibrations. FTIR has been a fast way to identify possible compounds in the sample while the copulation of XRD and XRF data can confirm the minerals and elements. AAS and ICPMS has a more sensitive detection thus providing a more precise total metal content data in low metal containing substances such as plant samples. The findings of this research hopefully will be useful for gold exploration method or further exploration in the study area.

6.2 Suggestions

Accessibility limitation should be overcome by using drone or team work exploration with sufficient safety equipment. Remote sensing principal component and multivariate analysis should be employed in any exploration project. Geophysical data should be incorporated for part of processes in gold manifestation. An area of confirmed gold deposition would be a better choice for biogeochemical study of gold such as gaining permission from the operating gold mines for sample and data collection.

Collaboration should also be made between multidisciplinary expertises. A more detailed ecological plotting should be carried out in the explored area with confirmed gold content. More soil and plant samples should be analysed and drawn into geochemical anomaly map overlaid with geological structures, alteration and geophysics map for the better validity of the mapping process.

With sufficient data, statistical model and conceptual model should be drawn for a better presentation of the relationship between the geological components and biological components. Plant sampling should be made on larger plant as their larger bioaccumulation amount thus easier to be detectable and characterized. Other than plants, microorganisms which are more specific in term of nutrition would be an easier choice in biogeochemical studies of gold despite the techniques required in bacteria screening and culture.

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