SCHOOL OF MATERIALS AND MINERAL RESOURCES ENGINEERING

UNIVERSITI SAINS MALAYSIA

GEOCHEMICAL AND MINERALOGICAL CHARACTERISTICS OF SELINSING GOLD DEPOSIT

By

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Dissertation submitted in partial fulfillment

of the requirement for the degree of Bachelor of Engineering with Honours

(Mineral Resources Engineering)

Universiti Sains Malaysia

JULY 2017

DECLARATION

I hereby declared that I have conducted, completed the research work and written dissertation entitled **"Geochemical and Mineralogical Characteristics of Selinsing Gold Deposit"**. I also declared that is has not been previously submitted for the award of any degree or diploma or other similar title of this for any other examining body or university.

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Date: 3 July 2017

ACKNOWLEDGEMENTS

I would like to acknowledge the following people, who all in their own special way assisted, guided, encouraged and supported me throughout this research and without them, this thesis would not have been completed.

Firstly, I am extremely grateful to the Allah S.W.T for giving me a good health and guidance throughout my entire life especially during completing my research. A special thanks to my supervisor, Assoc. Prof. Dr. Kamar Shah bin Ariffin for give me chance to do the research, sharing his experience, give me valuable guidance and willing to read this thesis.

I wish to thank Mr. Hasnor from Petrography Lab for his help with sample preparation of thin section and polish section. Mr. Shafiq, Mr. Junaidi and Mr.Zul for their assistance with the preparation sample before the sample being test. Mr. Kemuridan for testing my sample for XRF, Mr. Khairi for testing my sample for SEM and Mdm. Haslina for guide me to get the result from AAS analysis.

Most importantly, none of this could have happened without my family. To my parents and fmily who offered their encouragement throughout the research. Lastly, I want to give special thank to my classmate, other friends and those whom had offered help directly of indirectly.

Thanks for the help, prayful support and patience.

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ABBREVIATIONS

Au	Gold
Fe	Iron
Cu	Copper
Al	Aluminium
XRF	X-Ray Fluorescence
XRD	X-Ray Diffraction
AAS	Atomic Absorption Spectrometry
HCl	Hydrochloric Acid
HNO_3	Nitric Acid
DAR	Direct Aqua Regia
SX	Solvent Extraction
DIBK	Di-isobutyl Ketone
NaOH	Sodium Hydroxide

GEOCHEMICAL AND MINERALOGICAL CHARACTERISTICS OF SELINSING GOLD DEPOSIT

ABSTRACT

The average concentration of gold in the Earth's crust is mostly about 0.005 g/t, which is much lower than the other metallic metals. Therefore, systematic borehole logging has been conducted on borehole sample, covering about 2 holes. Sample A and E are coming from the same hole but different depth that is MSM DD036, while sample B,C and D are coming from holes MSM DD035. The objective is to identify the geology and potential gold mineralization in the prospect including observing the grade of the gold and others metallic element by knowing their concentration. In this research, pyrite, quartz and arsenopyrite are the major mineral in the gold particle as identified from the SEM analysis. Other than that, in order to do mineral identification, mineral can be know based on the peak pattern analysed by XRD and major oxide element that can be obtained from samples had been analysed by XRF. For chemical analysis in this research, the direct aqua regia was conducted to determine the grade of the other metallic elements such as Al, Cu and Fe that had high value of weight percentage, while the solvent extraction method was conducted only for tested Au the presence in the sample. From the experimental work conducted, pre-concentration such as solvent extraction can increase the gold detection under AAS analysis where large amount of iron will be removed from the solution. As a conclusion, gold in the hole MSM DD035 at Selinsing Gold Mine show the highest concentration than the hole MSM DD036.

CIRI- CIRI GEOKIMIA DAN MINERALOGI

DEPOSIT EMAS DI SELINSING

ABSTRAK

Kepekatan purata emas dalam kerak Bumi adalah kebanyakannya mengenai 0.005 g / t, yang jauh lebih rendah daripada logam logam lain. Oleh itu, pembukuan lubang gerudi yang sistematik telah dijalankan ke atas sampel lubang gerudi, yang meliputi kira-kira 2 lubang. Sampel A dan E yang datang dari lubang yang sama tetapi mempunyai kedalaman yang berbeza iaitu MSM DD036, manakala sampel B, C dan D yang datang dari lubang MSM DD035. Objektifnya adalah untuk mengenal pasti geologi dan potensi pemineralan emas selain untuk memerhatikan gred emas dan unsur logam yang lain-lain dengan mengetahui kepekatan mereka dalam sampel. Dalam penyelidikan, pirit, kuarza dan arsenopyrite adalah mineral utama dalam zarah emas seperti yang dapat dikenal pasti daripada analisis SEM. Selain daripada itu, untuk melakukan pengenalan mineral, mineral boleh diketahui berdasarkan corak puncak yang dianalisis oleh XRD dan unsur oksida utama yang boleh diketahui daripada sampel telah dianalisis oleh XRF. Untuk analisis kimia dalam kajian ini, larutlesap aqua regia telah dijalankan untuk menentukan gred unsur-unsur logam yang lain seperti Al, Cu dan Fe yang mempunyai nilai peratusan berat jisim yang tinggi, manakala kaedah pengekstrakan pelarut telah dijalankan hanya untuk menguji kehadiran Aurum(Au) dalam sampel. Daripada kerja-kerja eksperimen dijalankan, pra-kepekatan seperti pengekstrakan pelarut boleh meningkatkan pengesanan emas di bawah analisis AAS di mana jumlah besar besi akan dikeluarkan daripada penyelesaian. Kesimpulannya, emas dalam lubang MSM DD035 di Lombong Emas Selinsing menunjukkan kepekatan tertinggi daripada lubang MSM DD

CHAPTER 1

INTRODUCTION

1.1 Research Background

Gold occurs in a wide variety of settings, ranging from volcanic sinters and breccias to skarns and hydrothermal veins that may not be directly associated with intrusions and from dissemination in massive sulfides to placer and paleoplacer deposits. Veins dominated by native gold and quartz occur in ancient highly deformed and metamorphosed volcanic rocks. Veins dominated by gold and silver tellurides with quartz occur in this setting and in young (tertiary) volcanic rocks of the circum-pacific belt (Boyle, 1979).

Gold is the most metal known, but it is not the most valuable. Gold is the only metal that has a deep, rich, metallic yellow colour. Almost all other metals are silvery coloured. Gold is very rare in crustal rocks. It most commonly occurs in hydrothermal quartz veins, disseminated in some contact and hydrothermal metamorphic rocks, and in placer deposits. Gold easily accumulates in placer deposits condition.

Mineral formation process:

1. Precipitation from a fluid like H_2O or CO_2 – this can take place within the Earth by hydrothermal processes, diagenesis and metamorphism and at or near the Earth's surface as a result of evaporation, weathering or biological activity.
2. Sublimation from a vapour – this process is somewhat more rare, but can take place at a volcanic vent, or deep in space where the pressure is near vacuum.

3. Crystallisation from a liquid – this takes place during crystallisation of molten rock (magma) either below or at the Earth's surface.
4. Solid-solid reactions – this process involves minerals reacting with other minerals in the solid state to produce one or more new minerals.

Metamorphic gold mineralisation occurs when no direct magmatic input. Fluids derived from dehydration during prograde metamorphic reaction. Gold mineralization also occur when in range 250~400°C, 3~10 km depth but could be hotter-deeper and near neutral pH to moderately acidic.

Malaysia has a long history of widespread small-scale gold mining throughout the country, especially in the Central Belt of Peninsular Malaysia and highly potential region for the gold mining industry. The Central Belt consists mainly of Permo-Triassic, a low-grade metasediments, deep to shallow marine clastic sediments and limestone with abundant intermediate to acid volcanic and volcanoclastic.

Therefore, systematic borehole logging has been conducted on borehole sample, covering about 2 holes at Buffalo Reef, Selinsing Gold Mine. Sample A and E are coming from the same hole but different depth that is MSM DD036, while sample B,C and D are coming from holes MSM DD035.

The study area (Figure 1-1) is located along the north-south striking Raub-Bentong Suture – a major tectonic feature that across through Peninsular Malaysia and hosts the Central Gold Belt of Malaysia. The mineralization produced in a series of auriferous quartz vein and stockworks of quartz veinlets and as finely disseminated gold within sheared calcareous epiclastic sedimentary rocks.

1.2 Problem Statement

Everywhere throughout the world, gold has a unique value in the aspects of emotion, finance and culture, which underpins a continuous demand across generations. Gold is designed into jewellery and used to manage risk in financial portfolios and secure the wealth of nations, it is used in smart mobile phones, and medical diagnostics.

Figure 1-1: Location of Selinsing and Buffalo Reef Gold Mine

The high demand on gold can make more gold resources to be explored and exploited. In order to find a potential area, an accurate evaluation of gold grade in that area is very important to indicate area which contain low, medium and high grade of gold so as to promote an economical mining operation. Accurate quantification of gold in geological samples provides information to exploration geologists in the decision making process of whether a mine should be developed, maintained or closed. Inaccurate result will give wrong expectation towards the grade of gold thus affecting the future progress of mining operation.

Other than that, the ease with which a mineral is liberated from its host rock and recovered is influenced by the method of crushing and grinding as well as the variability in flotation parameters. Each of these mineral process is influenced by the mineral constituents of the host rocks and their textures.

While it is well known that the mineralogy and texture of a rock influence mineral processing behavior, previous studies in this field are descriptive, categorical and typically linked to a genetic interpretation. In contrast to this, the parameters extracted from physical rock tests that are routinely measured by mineral processors are numerical and quantified in a way that can be integrated into a working block model on site. Mineralogy and texture is required in order to link this two fields together.

Recent advances in the field of microscopy linked with increased computer processing capabilities mean that mineralogical and textural parameters can be quantified more readily. Previously, these data have been used by mineral processors in the analysis of mine feed, concentrates and tails after mining has commenced. Currently there are limited methods for the routine analysis and characterisation of mineralogical and textural attributes prior to the commencement of mining with the purpose of predicting variability in mineral processing behaviours.

1.3 Objectives of Research

The main purposes of this study are:

1. To identify gold mineralization and other minerals or elements that may presents in the rock samples taken from target area.
2. To determine the mineralogical characteristics of rock samples present in target area.
3. To observe the geochemical characteristics of rock samples present in target area.

1.4 Scope of Work

This research involved a detailed study carried out at Selinsing Gold Mine, Pahang and divided into two phase that is laboratory work phase and data processing and analyzing. Before start the laboratory work phase, the sample must be describe and classify based on the different hole from drilling.

The borehole logging is often used to identify and obtain geotechnical information. Sample received are named as well, MSM DD036 (88.7~88.9m) named as A, MSM DD036 (129.6~129.26m) named as E, MSM DD035 (210.3~210.5m) named as B, MSM DD035 (165.7~166.0m) named as C and MSM DD035 (174.5~174.7) named as D.

The laboratory works phase involves sample preparation including crushing, grinding, sampling and sieving. The analysis involve is X-Ray Fluorescence (XRF) for determination of elements content, Scanning Electron Microscope (SEM) is use to scan the minerals and mineral identification either it is ore or gangue mineral and Atomic Absorption Spectrometry (AAS) for the determination of grade of gold and other metallic elements that present in the samples.

Once the results are obtained, they will be processed and analyzed by using software Microsoft Excel 2007 for getting the graph plotting.

1.5 Thesis Outline

This thesis is organized into five main chapters:

Chapter 1 introduces briefly the coverage of the thesis, including the overview of the research background, problem statement, objectives and study sites of this research background.

Chapter 2 presents in detail about geology in the Selinsing Gold Mine, Pahang found in other earlier research.

Chapter 3 covers about methodology that being used from the first step to the last step until get the result.

Chapter 4 presents and discusses on whole results of the study.

Chapter 5 summarizes about the research and explain what is the recommendation from the research.

CHAPTER 2

LITERATURE REVIEW

2.1 Ore Genesis

The various theories of ore genesis explain how the various types of mineral deposits from within the Earth's crust. Ore genesis theories are dependent on the mineral or commodity. Ore genesis theories generally involve three components: source, transport or conduit, and trap. This also applies to the petroleum industry, which was first to use this methodology (Batchelor, 1994).

The source is required because metal must come from somewhere, and be liberated by some process. Transport is required first to move the metal bearing fluids or solid minerals into the right position, and refers to the act of physically moving the metal, as well as chemical or physical phenomenon which encourage movement. Trapping is required to concentrate the metal via some physical, chemical or geological mechanism into a concentration which forms mineable ore. The biggest deposits are formed when the source is large, the transport mechanism is efficient, and the trap is active and ready at the right time (Batchelor, 1994).

2.1.1 Ore Genesis Process

The major theories of one genesis process are divided into internal processes and surficial processes (Evans, 1992).

a) Internal processes

These processes are involved the physical phenomena and chemical reactions internal to magmas, generally in plutonic or volcanic rock. Internal processes can be classified into several types such as magmatic processes, hydrothermal processes and metamorphic processes (Evans, 1992).

i) Magmatic processes:

Process of precipitation of ore minerals either as a major or minor constituent of igneous rocks are in the form of disseminated grains or segregation. Magmatic segregation is defined as ore that crystallized directly from magma. Process of separation of ore minerals by fractional crystallization separates ore and non-ore minerals according to their crystallization temperature. As early crystallizing minerals form they incorporate certain elements, some of which are metals. These crystals may settle onto the bottom of the intrusion, concentrating ore minerals there. Chromite and magnetite are ore minerals that form in this way. Sulfide ores containing copper, nickel or platinum may form from the process of liquid immiscibility. As a magma changes, parts of it may separate from the main body of magma. Two liquids that will not mix are called immiscible, oil and water is an example. In magmas, sulfides may separate and sink below the silicate-rich part of the intrusion or be injected into the rock surrounding it. These deposits are found in mafic and ultramafic rocks (Thorne and Edwards, 1985).

ii) Hydrothermal processes:

These processes are the physicochemical phenomena and reactions caused by movement of hydrothermal waters within the crust, often as a consequence of magmatic intrusion or tectonic upheavals. The foundations of hydrothermal processes are the source-transport-trap mechanism. Sources of hydrothermal solutions include seawater asn meteoric water circulating through fractured rock, formational brines (water trapped within sediments at deposition) and metamorphic fluids created by dehydration of hydrous minerals during metamorphism. Metal sources may include a plethora of rocks.

However, most metals of economic importance are carried as trace elements within rock-forming minerals, and so may be liberated by hydrothermal processes. This happens because of incompatibility of the metal with its host mineral, for example zinc in calcite, which favours aqueous fluids in contact with the host mineral during diagenesis. Also occur because of solubility of the host mineral within nascent hydrothermal solutions in the source rocks, for example mineral salts (halite), carbonates (cerussite), phosphates (monazite and thorianite) and sulfates (barite). It also because of elevated temperatures which causing decomposition reactions of minerals (Evans, 1992).

Transport by hydrothermal solutions usually requires a salt or other soluble species which can form a metal-bearing complex. These metal-bearing complexes facilitate transport of metals within aqueous solutions, generally as hydroxides, but also by processes similar to chelation. This processes is especially well understood in gold metallogeny where various thiosulfate, chloride and other gold-carrying chemical complexes. The majority of metals deposits formed by hydrothermal processes include sulfide minerals, indicating sulfur is an important metal-carrying complex (Barnes, 1979).

Sulfide deposition within the trap zone occurs when metal-carrying sulfate, sulfide or other complexes become chemically unstable due to factors of the falling temperature which renders the complex unstable or metal insoluble, loss of pressure which has the same effect, reaction with chemically reactive wall rocks, usually of reduced oxidation state, such as iron bearing rocks, mafic or ultramafic rocks or carbonate rocks and also factor of degassing of the hydrothermal fluid into a gas and water system, or boiling, which alters the metal carrying capacity of the solution and even destroys metal-carrying chemical complexes (Barnes, 1979).

Metal can also become precipitated when temperature and pressure or oxidation state favour different ionic complexes in the water, for instance the change from sulfide to sulfate, oxygen fugacity, exchange of metals between sulfide and chloride complexes.

iii) Metamorphic processes:

Ore deposits formed by lateral secretion are formed by metamorphic reactions during shearing, which liberate mineral constituents such as quartz, sulfides, gold, carbonates and oxides from deforming rocks and focus these constituents into zones of reduced pressure or dilation such as faults. This may occur without much hydrothermal fluid flow, and this is typical of podiform chromite deposits. Metamorphic processes also control many physical processes which form the source of hydrothermal fluids, outlined above.

b) Surficial processes

Surficial processes are the physical and chemical phenomena which cause concentration of ore material within the regolith, generally by the action of the environment. This includes placer deposits, laterite deposits and residual or eluvial deposits. The physical processes of ore deposits formation in the surficial realm include erosion, deposition by sedimentary processes including winnowing which is density separation (eg: gold placers), weathering via oxidation or chemical attack of a rock either liberating rock fragments or creating chemically deposited clays, laterites or manto ore deposits and also include deposition in low-energy environments in beach environments.

Table 2-1: Processes that involve in surficial process

Process	Description
Mechanical accumulation	Concentration of heavy, durable minerals into placer deposits.
Sedimentary precipitates	Precipitation of particular elements in suitable sedimentary environments with or without the intervention of biological organism.
Residual processes	Leaching from rocks of soluble elements leaving concentrations of insoluble element in the remaining material.
Secondary or supergene enrichment	Leaching of valuable elements from the upper parts of mineral deposits and their precipitation at depth to produce higher concentration.
Volcanic exhalative	Exhalations of hydrothermal solutions at the surface usually under marine condition and generally producing stratiform ore bodies.

2.2 Gold Formation

Gold is formed in a wide variety of hydrothermaldeposits, which may be eroded and the gold concentrated by hydraulic processes in riversand on the beaches, and deposited as sedimentary placer deposits. In hydrothermal deposits, gold is most commonly associated with silver and basemetals, copper, lead and zinc. Most of these deposits are quartz veins deposited from hydrothermal fluids in fault zonesat medium (mesothermal) or shallow (epithermal) depths in the crust (Ariffin, 1995).

2.2.1 Placer Deposits

The high density and chemical stability of gold enables it to be mechanically concentrated in river and beach environments and preserved in placer deposits. These have accounted for more than two-thirds of the total world goldsupply. Quartz pebble conglomerate pyritic paleoplacer deposited in braided streams and alluvial fans during the Precambrian. The conglomerates are clast supported with well rounded pebbles of quartz, cherts and locally pyrite, in a matrix of quartz, mica, chlorite, pyrite and fuchsite. They contain native gold, pyrite, uraninite, brannerite and traces of platinum group of mineral (Ariffin. 1995).

Young placers consist of goldbearing gravel and sand, and their consolidated equivalents, deposited in alluvial, beach and fluvioglacial environments during the Late Cenozoic. These were the deposits worked during the gold rushes. Gravity and hydraulic action concentrate gold and other heavy minerals at location where the water velocity decreses markedly, such as on the inside of meanders, below rapids and falls, in the boolders, beneath vegetation mates, along strandlines on beaches, and in “traps” such as natural riffles in the river bed formed by fractures or joints in the bedrocks.

Rich young placer deposits result from several cycles of erosion, transportation and deposition. In some placers, gold may be redistributed and reconcentrated by chemical migration andaccretion process. Native gold occurs along with other heavy minerals such as magnetite, ilmenite, garnet, zircon, rutile, monazite and locally cassiterite and platinum group elements. Grade of median size young placer is less than 0.5 g/t (Ariffin, 1995).

Detrital gold is insoluble at surface P-T conditions. It becomes caught up in streams which carry it before it drops out due to its weight. It is then sorted which known as the winnowing process (Ariffin, 1995).

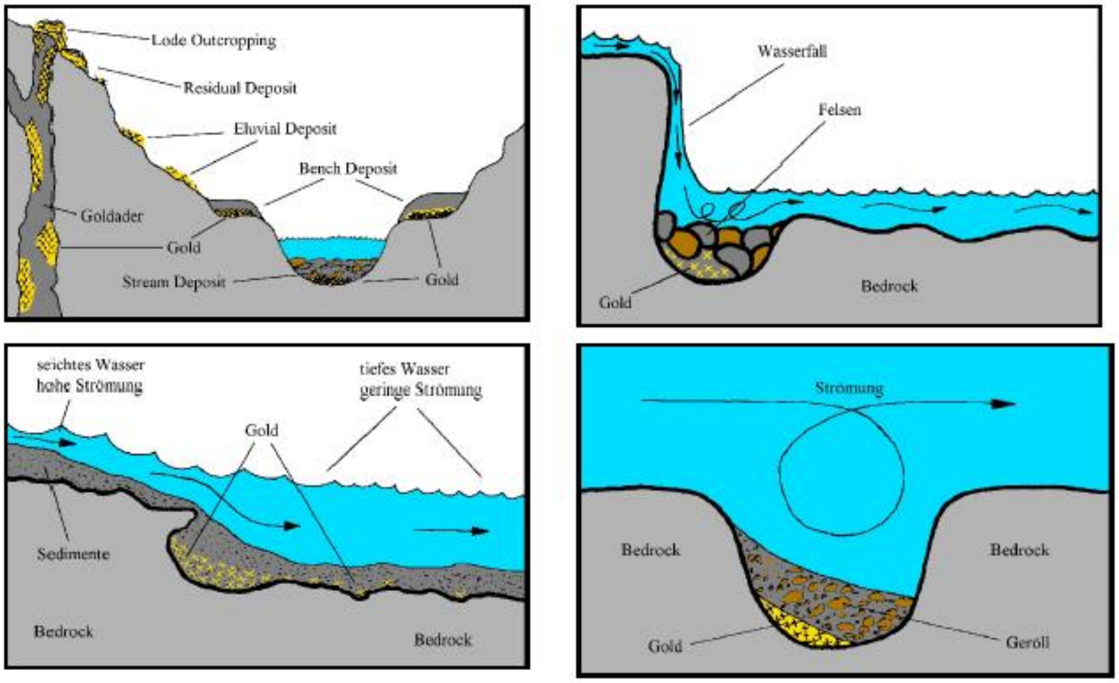

Figure 2-1: Young placer mineralogy

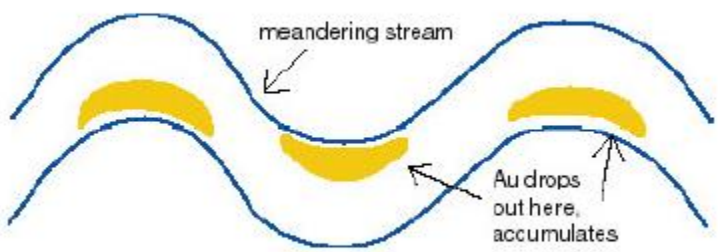

Figure 2-2: Insoluble of gold at a surface

2.2.2 Lode Gold and Mesothermal Deposits

These are quartz lode deposits formed in fault and shear system at crustel level within and above the brittle-ductile transition zone, at depths of 3-12 km and temperatures from 200-400 °C. Deposits may have a vertical extent of up to 2 km, and lack pronounced zoning. Ribbon banded vein textures are common and were formed by "crack-seal" process involving episodic reopening of the veins, fluid flow and mineral deposition. The genesis of the deposits is controlversial but most current workers favor a metamorphogenic-deformational origin, although some deposits may have had a magmatic influence in their genesis (Ariffin, 1995).

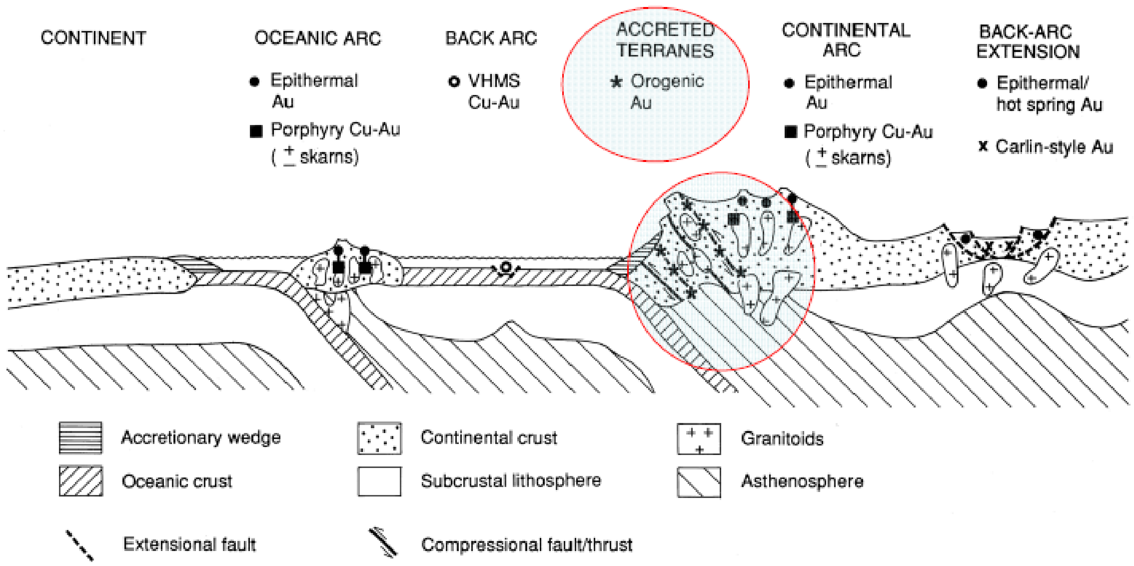

Figure 2-3: Tectonic setting of gold-rich epigenetic mineral deposits

Figure 2-3 explain that epithermal veins and gold rich porphyry and skarn deposits form in the shallow (<5km) and parts of both island and continental areas in compressional through extensional regimes. The epithermal veins, as well as the sedimentary rock-hosted type Carlin ores, also are emplaced in shallow regions of back-arc crustal thinning and extension. In contrast, the so-called 'mesothermal' gold ores termed orogenic gold on this diagram are emplaced during compressional to transpressional regimes and throughout much of the upper crust, in deformed accretionary belts adjacent to continental magmatic arcs. (After Grove et al., 1998)

Mesothermal deposits are the green lode gold deposits consists of gold-bearing quartz lodes found in Late Archean and Mesozoics greenstone belts. They are localized along or adjacent to major structural crustal breaks orsuture zones, related to terrane collisional boundaries. The lodes are hosted in mafic and ultramafic volcanic rocks, banded ironformations, greywacke, and conglomerate that have been metamorphosed to green schist and locally amphibolite facies. Wallrock alteration is characterized by quartz-pyrite-muscovite assemblages adjacent to the veins (usually within a metre) enclosed within a broader zone of carbonate alteration. Mineralogy of this mesothermal deposits are the veins contain quartz, carbonate, pyrite, arsenopyrite and minor native gold and base metals (Ariffin, 1995).

2.3 Geology of Central Belt

Peninsular Malaysia can be separated into three main belts which are West, Central and East Belts of Geological Province (Goh et al., 2006: Metacalfe, 2000; Yeap, 1993; Teoh et al., 1987). Gold is widely distributed in Peninsular Malaysia especially in the Central Belt including Pahang and Kelantan (Ariffin & Hewson, 2007). The largest gold deposits that has been discovered is laying within the Central Gold Belt which is in Ulu Sokor within District of Tanah Merah, Kelantan and it was established as the major producer of gold for more than 100 years (Li et al.,2014).

The Central Gold Belt is a very forthcoming district for gold with an assortment of mineralization sorts and has a long history widespread diminutive-scale alluvial gold mining all through Peninsular Malaysia (Ariffin & Hewson, 2007; Li et al., 2010,2011). Some of primary ores were already operated by mining companies since four decades ago, such as the deposits of Selinsing, Penjom Raub and Ulu Sokor (Figure 2-4).

Most of the gold deposits in the Central Belt were classified as mesothermal lode types and orogenic deposits due to the geologic and tectonic setting (Ariffin, 2012; Ariffin & Hewson, 2007; Li et al., 2010, 2011; Makoundi et al., 2014). The mesothermal gold lode occurs in quartz rich-carbonate veins and also the surrounding hydrothermal alteration,then being disseminated in the altered host rocks before experienced extensive deformation, metamorphism, and magmatic events which provided a medium for the catch gold (Ariffin, 2012). The orogenic gold deposits also shared the same characteristic of mesothermal lode (Goldfarb et al., 2001; Groves et al., 1988,2003).

Metcalfe (2000, 2013a, 2013b) and Metcalfe & Allen, 2000 state that the Western Belt is part of the west Sibamasu Terrane while the Central and Eastern Belts is part the east Sukhothai Arc or known as East Malaya Fold Belt. During Late Permian, Paleo-Tethys oceanic crust subducted beneath the Indochina Block causing a collision between Sibamasu and Indochina blocks along the Raub-Bentong Suture Zone. The process evolved in the early to middle Triassic and ended in the Late Triassic (Khin et al., 2014; Mecalfe,2011).

Another suggestion has been made saying that the collision of Sibamasu-Indochina occurred before the Late Triassic and probably in the Late Permian to early Triassic (Metcalfe, 2011; Sevastjanova et al., 2011). This was accompanied by active magmatic process which leads to the formation of the Permian and Triassic granitoids of the two provinces in the main range and the Eastern Belt (Hutchison et al., 2009; Metcalfe, 2011; Schwartz et al., 1995).

2.4 Property Description and Location

2.4.1 Property Location

The Selinsing Gold Mine Project is located at Bukit Selinsing Koyan, approximately 65 km north of Raub and 30 km west of Kuala Lipis on the lineament as the Raub-Bentong Suture. Selinsing is located approximately 2 hours drive from Kuala Lumpur the capital of Malaysia on a sealed highway in Pahang State, which is the largest gold producing state in Malaysia (Figure 2-4). (John R.W. Fox et al.,2012)

Figure 2-4: Central Gold Belt of Malaysia and locations of significant mines

2.5 Gold Mining History

2.5.1 Selinsing

Historic mining of visible gold at Selinsing by crude means probably occurred for centuries prior to 1888, when British companies began production on a larger scale utilizing machinery and metallurgy, with intermittent mining continuing at Selinsing up until June 2007 when Monument acquired the Selinsing project. Full operation at The Selinsing Gold Mine had started in September 2010. The plant there consists of two stages of crushing, with a single stage ball mill operating in closed circuit, having a throughput of approximately 1,000 t/day. A gravity recovery circuit is used, consisting of a Knelson centrifugal

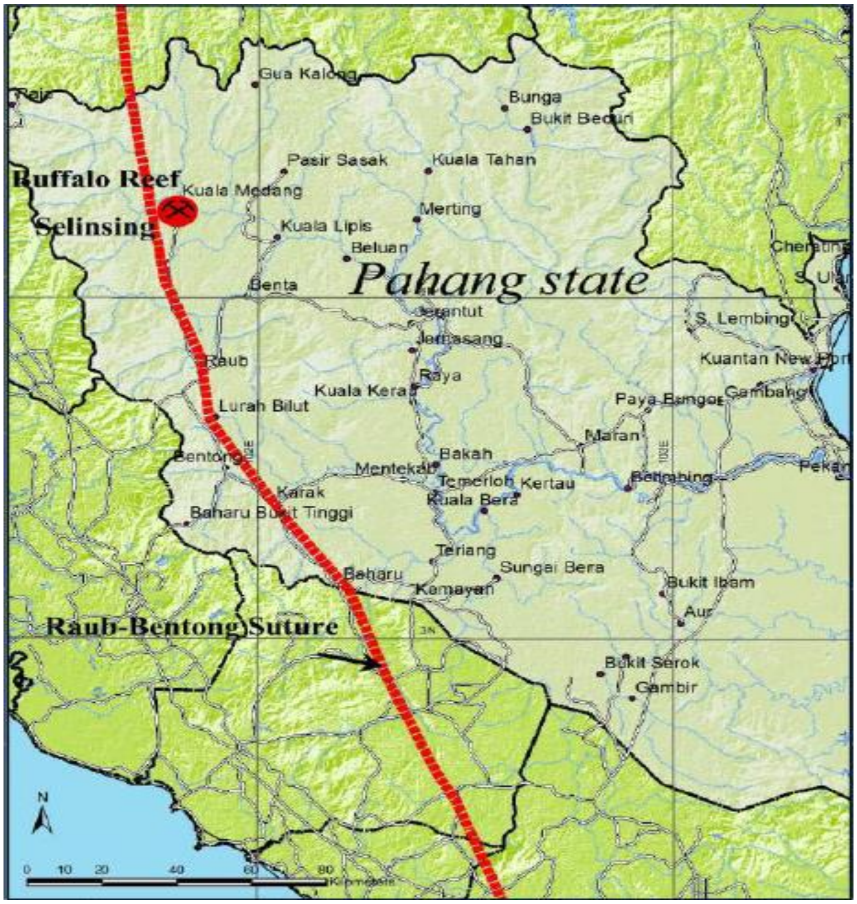

Figure 2-5: Pahang State, showing Selinsing-Buffalo Reef and Raub-Bentong Suture

concentrator that operates on a split from the mill cyclone underflow. The Knelson concentrator is subjected to an Acacia high intensity leach with the leached concentrate returned to the ball mill. The mill cyclone overflow discharges to a six stage carbon in leach (CIL) cyanidation circuit, with a targeted grind of 80% passing 75μm and a 36 hour retention time. Loaded carbon is advanced through the leach circuit, collected, then stripped of precious metals with hot caustic, reactivated and recycled. The pregnant solution form the Acacia reactor and from the stripped carbon is sent to the refinery for electrowinning and subsequent production of Dore. The leached CIL slurry is discharged to the tailing impoundment facility.

The Selinsing gold deposit is located in northwest Pahang, approximately about 50 km north of Raub Town in central Malaysia (Figure 2-5). The Selinsing deposit and other major gold deposits in the region such as Buffalo Reef, Ulu Sokor, Penjom, Pulai and Raub deposits are located to the east of the Bentong-Raub Suture Zone (Figure 2-6). The Selinsing deposit has a long mining history tracing back prior to the late 19^{th} Century. Currently, the Selinsing Gold Mine Project contains an indicated mineral resource of 4.82 million tons at 1.49 g/t Au, using a cut-off grade of 0.59 g/t Au for contained gold of 231,000 oz, and an inferred mineral resource of 10.32 million tons at a grade of 1.17 g/t Au for contained ounces of 388,000 at a similar cut-off grade.(John R.W. Fox et al.,2012).

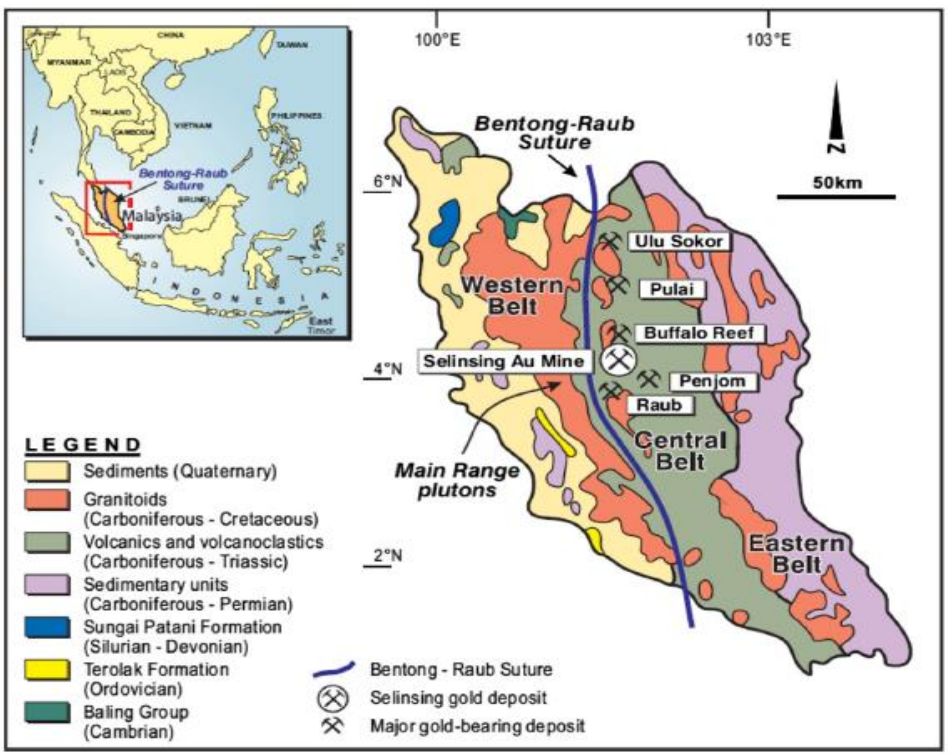

Figure 2-6: Map showing the location of the Selinsing and the other gold deposits, Bentong-Raub Suture Zone, the Western, Central and Eastern Belts in Peninsular Malaysia

2.5.2 Buffalo Reef

The Buffalo Reef area is located at the eastern boundary of the Bentong and Raub Groups in Western part of the Pahang State, Malaysia. The western highland is underlain by conglomerates belonging to Bentong Group. The conglomerates contain rounded clasts with diameter up to 10 cm with 30-40% of arenaceous matrix. They form massive outcrops with ill-defined stratification. (John R.W. Fox et al.,2012).

2.6 Study sites

2.6.1 Geologic setting and mineralization

2.6.1.1 Regional Geology

The regional geological setting that hosts both the Selinsing and Buffalo Reef gold deposits is very well detailed in E.B.Yeap's 1993 paper titled " *Tin and gold mineralization in peninsular Malaysia and their relationships to the tectonic development*", which is a standard for geological summary written by Martin, I.D. October 1995.

Peninsular Malaysia can be divided into two main regional blocks separated by the Raub-Bentong Line which is a major suture zone. This fault zone divides the Sibumasu Block (Western Block) in the west from the Manabor Block (Eastern Block) in the east (Yeap, E.B.1993)(Figure 2-7). By the late Carboniferous, the Western Block was attached to a continent, possibly Gondwana, and the eastern margin of this was occupied by a shelf which quickly gave way to open ocean.

By late Carboniferous to early Permian, westward subduction of oceanic lithosphere beneath the Western Block close to the Raub-Bentong suture was initiated. Riding on this oceanic lithosphere were many continental fragments which accreted onto the Eastern

Block to form the Timur and Tenggara Foreign Terranes. This subduction led to the granitic intrusion that now makes up the Western Tin Belt.

Subduction ceased temporarily and the subduction zone shifted to the east. By the Early Triassic, subduction was reinitiated along a new zone to the east of the earlier zone. With time, gold-bearing fluids are believed to have been released as oceanic lithosphere was subducted beneath the newly accreted wedges of shelf carbonates and marine sediments. These fluids migrated upwards along large regional fractures cutting the sediments that were newly accreted onto the eastern margins of the Western Block and deposited the gold deposits which constitute Yeap's "Gold Belt 2". Yeap's gold belt 2 or the Berching-Raub-Bersawah Gold Belt is the best defined of the four gold belts. The gold mineralisation typically takes the form of veins, reefs and lodes striking from 345° to 360° in moderately to strongly metamorphosed sediments (John R.W. Fox et al.,2012).

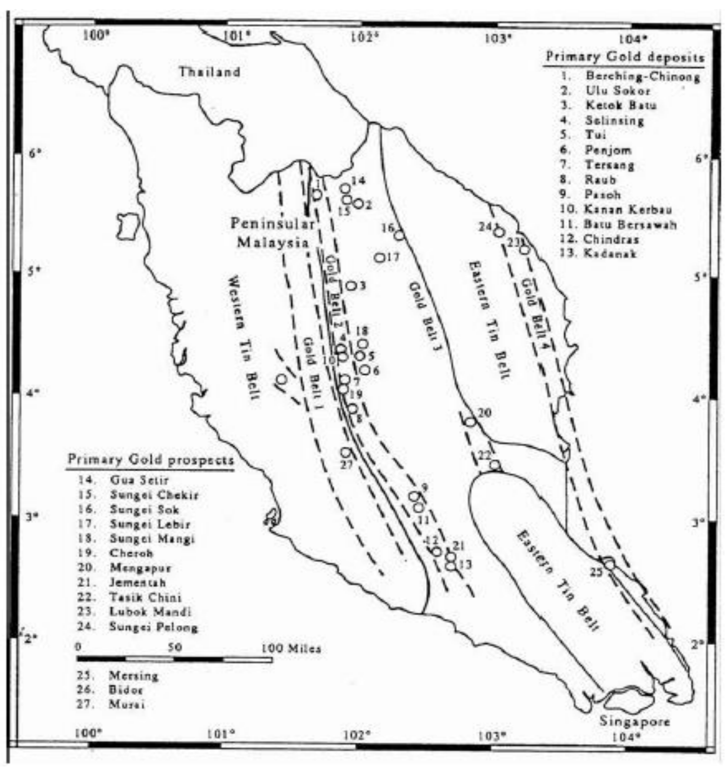

Figure 2-7: Peninsular Malaysia mineral occurrences (from Yeap, 1993)

2.6.1.2 Property Geology: Selinsing

The Selinsing deposit is hosted by a 30 to 50 metre thick shear zone that dips steeply towards mine grid east (082° true grid) at angles between 55° and 75°. This zone or "envelope" of sheared rocks has been variably mineralised ad intruded by gold-bearing quartz veins and stockworks of quartz veinlets. The quartz veins are likely to have been emplaced along individual fault surfaces. The faulting is thought to be essentially dip-slip reverse thrusting caused by compression from the east. Strike-slip movement is not thought to be significant although a north-westerly structure post dating the gold mineralisation is evident and could have a strike-slip component. The host rocks for the shear zone consists of a series of finely interbedded argillites and very fine-grained arenites. Also present are sequences of quartz rich, variably silicified sediments of likely tuffaceous origin, which are referred to as "felsic tuff" and a few thin beds of quartzite conglomerate. These country rocks are collectively known as the mine sequence series (John R.W. Fox et al.,2012).

The mine sequence sediments are deep marine epiclastic sediments laid down in quiet conditions and are thought likely to be of volcanogenic origin. The mine sequence has undergone low grade regional burial metamorphism which is seen by the development of chlorite in some of the country rocks, more notably the felsic volcanics.

These country rocks are host to the shearing which has transported the gold-bearing fluids. One interpretation is that the mine sequence has a true thickness of about 200 metres but as very little is known about the position of the footwall contact, it is difficult to distinguish between the mine sequences in the field without detailed petrographic studies due to the fine-grained nature of the host rocks. A second interpretation is that within the shear zone, repetition of these units by shearing creates a structural thickening of the sequence (John R.W. Fox et al.,2012).

The hanging wall rocks are a distinctive sequence of predominantly “dirty”, competent, well-bedded, dark coloured limestones. To the base of the limestones is a small unit of black well-bedded carbonaceous shale, sometimes calcareous in places. The contact of these units with the mine sequence is thought to be a tectonic or faulted contact due to the unconformable nature of the bedding on either side of the contact. The contact itself is characterised by large water-filled clay-lined cavities. Little is known about the footwall contact because the base of the mine sequence has not been extensively explored. However the footwall does consist of the same type of “dirty” grey-black limestones as in the hanging wall and it is suspected that these units are the same and have been repeated due to the faulting which hosts the gold mineralisation. This means that the less competent mine sequence units have allowed the shearing to occur through these units due to rheological contrasts between the limestones and the argillites and arenites. The hanging wall limestones have locally developed folds resulting from easterly compression and underground, the limestones are reported to have been seen to become calcareous argillites along strike in the same bedding plane.

Within the shear zone, there are distinctive tectonic-deformed rock types, the most noticeable of which are cataclastics and mylonites. Variation in the degree of shearing between locales has produced a set of tectonic rocks from both brittle regimes (cataclastics) and ductile regimes. It is likely therefore that this part of the fault zone was developed characteristics that conform to the brittle-ductile transition zone occurring at 10 to 15 km depth. Gold and sulphide mineralization is associated with these rock types as well as intensive replacement by quartz and calcite gangue minerals. Pressure /

temperature studies on fluid inclusions in quartz confirm a depth of about 10 km (John R.W. Fox et al.,2012).

2.6.1.3 Property Geology: Buffalo Reef

The Buffalo Reef deposit occurs approximately 1 km to the east of the Raub-Bentong Suture – a major geological feature previously described in the Regional Geology (Figure 2-4). The Buffalo Reef area is dominated by an eastern assemblage or argillite and limestone of Permian age in faulted contact with a western assemblage of conglomerates and sandstones of Devonian age. Low grade regional metamorphism up to Greenschist facies occurs throughout the area. The sedimentary rocks have subsequently been intruded by granitic bodies of approximately Jurassic age. Outcropping rocks of these intrusive bodies occur to the east of Buffalo Reef and generally from elevation highs.

The dominant structural feature present is a 200 m wide, north-south striking shear zone, with an apparent sinistral sense of displacement, which parallels the tectonic Raub-Bentong Suture to the west. The host rocks within the shear zone are composed of graphitic shale with minor interbedded fine-grained sandstone and tuffaceous rock. Bedding within the sedimentary rocks typically dips 65-75 degrees to the east and strike towards a bearing of 330 to 360 degrees.

The dominant rock types within the Buffalo Reef area are Permian age argillites and limestones, which are cross-cut by later granitic to intermediate intrusive rocks. Gold mineralization is structurally controlled within a 200 m wide shear zone that trends sub-parallel to the regional Raub-Bentong Suture to the west. Gold occurs within veins and is typically associated with pyrite, arsenopyrite and stibnite (John R.W. Fox et al.,2012).