SCHOOL OF MATERIALS AND MINERAL RESOURCES ENGINEERING

UNIVERSITI SAINS MALAYSIA

MINERALOGY AND GEOCHEMICAL STUDY OF AIR PIAU, KELANTAN GOLD PROSPECT (DRILL CORE)

by

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DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitle **'Mineralogy and Geochemical Study of Air Piau, Kelantan Gold Prospect (Drill Core)'**. I also declare that it has not been previously submitted for the award of any degree or diploma or other similar title any examining body or University.

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Date: 25th June 2018

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LIST OF ABBREVIATION AND SYMBOL

XRF	X-Ray Fluorescence
XRD	X-Ray Diffraction
AAS	Atomic Absorption Spectrometry
SEM	Scanning Electron Microscope
EDX	Energy-dispersive X-ray Spectroscopy
LOI	Loss of Ignition
DIBK	Di-Isobutyl Ketone
Zn	Zinc
Fe	Iron
Au	Gold
HCl	Hydrochloric Acid
HNO_3	Nitric Acid
g	Gram
km	Kilometre
g/t	Gram per tonnes
F	Fahrenheit
°C	Degree Celsius
mm	Millimetre
ppm	Part per million

KAJIAN MINERALOGI DAN GEOKIMIA PROSPEK EMAS DI AIR PIAU, KELANTAN (TERAS GERUDI)

ABSTRAK

Kepekatan purata emas dalam kerak Bumi kebanyakannya kira-kira 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. Jumlah kedalaman lubang adalah 100 m, jadi setiap sampel diambil setiap 25 m yang akan mendapat empat sampel untuk dianalisis. Selain itu, sampel telah dipilih berdasarkan ciri-ciri dan rupa yang ditunjukkan sepanjang kedalaman. Objektifnya adalah untuk mengenal pasti geologi dan potensi pemineralan emas dalam prospek selain untuk memerhatikan gred emas dan unsur logam yang lain-lain dengan mengetahui kepekatan mereka dalam sampel. Dalam kajian ini, mineral seperti pirit, kuarza dan arsenopyrite adalah mineral utama dalam zarah emas yang dikenal pasti dari analisis SEM-EDX. Selain itu, mineral kuarza adalah paling tinggi hasilnya yang dapat diketahui berdasarkan pola puncak yang dianalisis oleh XRD, diikuti dengan mineral pirit dan rutil. Unsur oksida utama yang dapat diperolehi daripada sampel adalah Fe_2O_3, SiO_2 dan TiO_2 yang telah dianalisis oleh XRF. Untuk analisis kimia dalam kajian ini, emas dalam sampel B (kedalaman pada 52.2m) di Air Piau menunjukkan kepekatan tertinggi daripada sampel lain yang telah dianalisis oleh analisis AAS. Sebagai kesimpulan, kaedah terbaik untuk menganalisis emas adalah dengan menggunakan ICP-OES kerana had pengesanan lebih baik daripada analisis AAS. Ini sesuai untuk menganalisis sampel eksplorasi yang tidak menjanjikan sebarang nilai tinggi.

MINERALOGY AND GEOCHEMISTRY STUDY OF AIR PIAU, KELANTAN GOLD PROSPECT (DRILL CORE)

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. Total depth of borehole is 100 m, so each sample are taken every 25 m which will get four samples to be analysed. Besides that, the samples were being chosen based on the characteristic and appearance that they showed along the depth. The objectives are to identify the geology and potential gold mineralization in the prospect including observing the grade of the gold and other metallic element by knowing their concentration. In this research, minerals such as pyrite, quartz and arsenopyrite are the major mineral in the gold particle such identified from the SEM-EDX analysis. Other than that, quartz was the highest result that can be known based on the peak pattern analysed by XRD, followed with mineral pyrite and rutile. Major oxide element that can be obtained from samples were Fe_2O_3, SiO_2 and TiO_2, that had been analysed by XRF. For chemical analysis in this research, gold in sample B (depth at 52.2m) at Air Piau showed the highest concentration than other samples which had been analysed by AAS analysis. As a conclusion, the best method to analyse gold was by using ICP-OES because the detection limit was better than AAS analysis. This was suitable for analysing exploration sample which not promising any high value.

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 sulphides 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 deep, rich, metallic yellow colour and almost all other metals are silvery coloured. Gold commonly occurs in hydrothermal quartz veins, disseminated in some contact and hydrothermal metamorphic rocks and in placer deposit. Gold also easily accumulates in placer deposits environment.

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 rarer 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 and highly potential region for the gold mining industry. The Central Belt consists mainly of Permo-Triassic, a low-grade meta-sediment, deep to shallow marine clastic sediments and limestone with abundant intermediate to acid volcanic and volcanoclastic.

1.2 Study Area

The samples in this study are gold drill core sample from the same hole but the different depths. The sample was grabbed at Air Piau site belongs to PMBK AZ–ZAHAB Sdn. Bhd which located at Lot 179 Jalan Dewan Beta Hilir, Kg Gaung Belukar, 15100 Kota Bharu, Kelantan, Malaysia (GPS location of 6°02'03.3"N 102°12'55.4"E). The mining site is accessible by land and will takes around one hour of driving from Kg Gaung Belukar and around 5 hours of driving with the distance of 346 km from Universiti Sains Malaysia, Nibong Tebal, Pulau Pinang to arrive Kg Gaung Belukar. The grabbed sample taken brought to USM pilot laboratory to be characterized and processed.

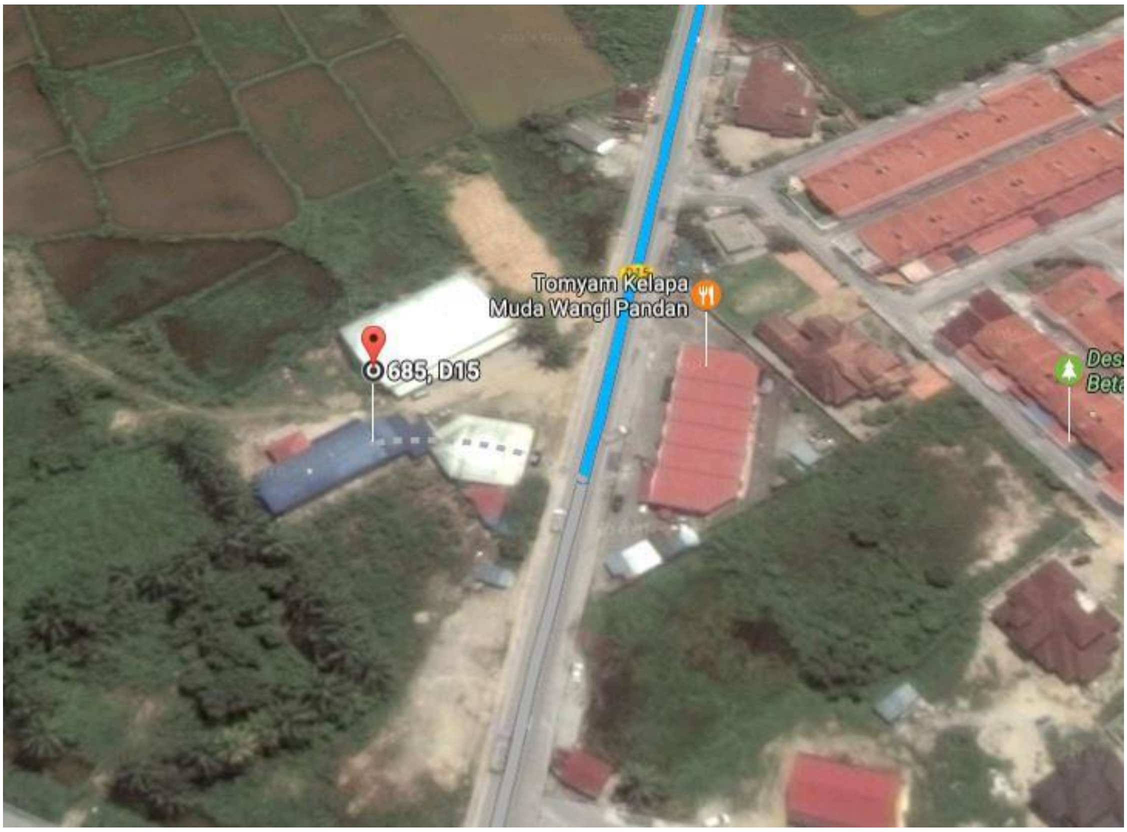

Figure 1.1: Satellite image of PMBK AZ-ZAHAB operation office

Therefore, systematic borehole logging has been conducted on borehole sample, covering a hole at APDD-04, Air Piau's site. These samples are coming from the same hole but different depth which are MD1960 AP (23.3m), MD1994AP (52.2m), MD2018AP (75.5m) and MD2042AP (100.5m).

The study area is located at West Kelantan that covering geological map for Sheet 22 (Tanah Merah) with the scale 1:63360. This area is bounded by lines longitude 05°30'N to 05°50'N and latitude 101°0'E to 103°0'E. Located 30 kilometres away from the Tanah Merah Centre, the area is surrounded by palm oil plantation and rubber estate. Sungai Bertam is the main stream. The main road is Tanah Merah-Jeli. The unsealed road, laterite, and logging track connect the study area to the main road. The location of study area is shown in Figure 1.2.

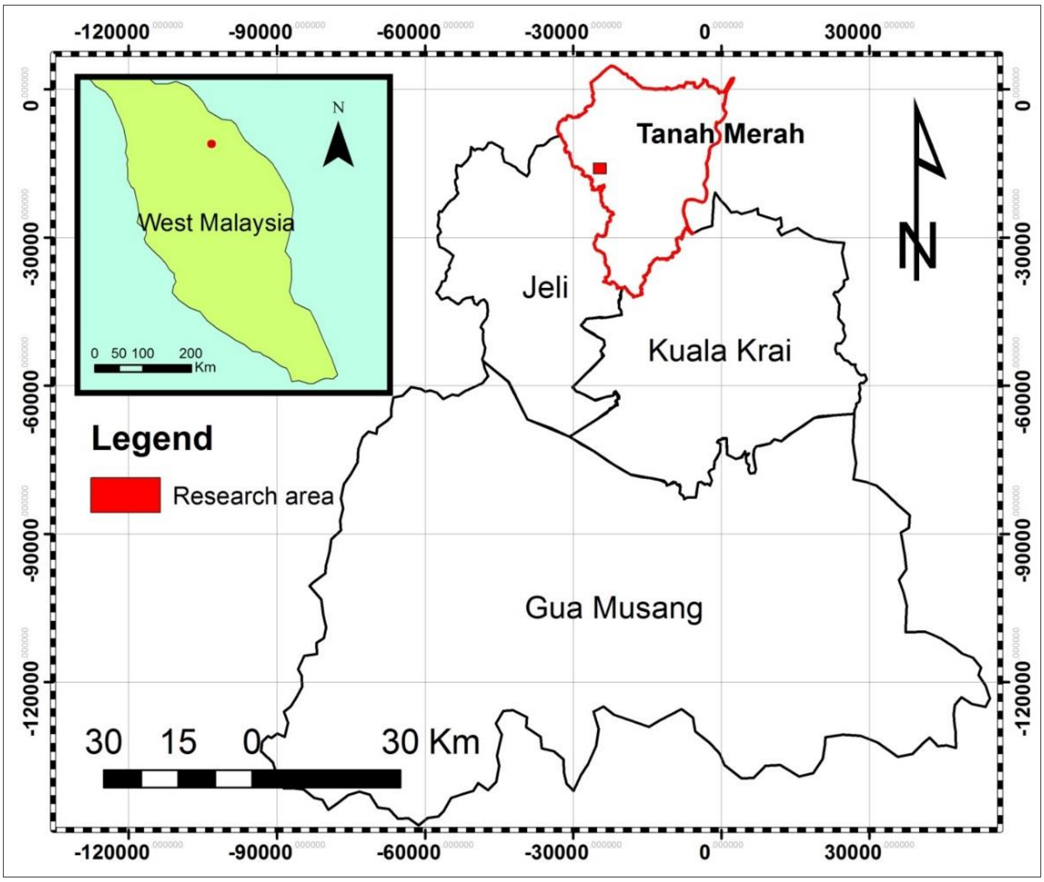

Figure 1.2: Location of Air Piau gold mineralization prospect (modified after unpublished report of PMBK AZ-ZAHAB, 2010)

1.3 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 jewelleries and used to manage risk in financial portfolios and secure the wealth of nations; it is found in smart mobile phones and advanced medical diagnostics. The interest in gold is still very substantial, due to social needs, investment and also in terms of gifting, particularly during the festive seasons.

The high demand on gold promotes more gold resource 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 provide vital information to exploration geologists in the decision-making process whether a mine should be developed, maintained, or closed. Inaccurate result will give wrong evaluation towards the grade of gold thus affecting the future progress of mining operation.

During reconnaissance survey that has been done by the exploration team of the PMBK AZ-ZAHAB, boulder of rich quartz found along the hill of Air Piau, Kelantan. Some quartz vein and outcrops are already found at certain area. Information about the progress and result of the exploration is collected from unpublished companies reported. The discovery of these rocks has led the geologist to explore the possibility of subsurface mineralization in this area. Hence a research project is carried out with the aim to identify the geology, and potential gold mineralization of the area.

1.4 Objectives

The main purposes of this study are:

i. To identify gold mineralization and associate minerals that present in the rock samples taken from Air Piau’s prospect based on drill core.

ii. To study the mineralogical characteristics of rock samples, present in Air Piau’s prospect.

iii. To study the geochemical characteristics of rock samples, present in target area.

1.5 Scope of Work

This research involved a geological study carried out at Air Piau, Kelantan and divided into two phase that are laboratory work phase and data processing and analysing. Before the laboratory work phase is started, the sample must be described and classify based on the different depth from the drill core sample based in drill hole samples.

The borehole logging is often used to identify, obtain geotechnical information and subsurface geology (rock, minerals and geochemical composition). The samples are given from the fourth borehole which named APDD-04 and the total depth is 100.5m. Samples received are named:

i. MD1960 AP as A from 23.0 m to 23.3 m

ii. MD1994AP as B from 52.0 m to 52.2 m

iii. MD2018AP as C from 75.4 m to 75.6 m

iv. MD2042AP as D from 100.3 m to 100.5 m

The laboratory preparation phase involved sample preparation including crushing, grinding, sampling and sieving. The analysis involved are:

i. X-Ray Fluorescence (XRF) for determination of elements content

ii. SEM-EDX for mineral identification either it is ore or gangue

iii. Atomic Absorption Spectrometry (AAS) use for the determination of grade of gold and other metallic elements that present in the samples.

The data are the proceed and presented in graphic plots (using Microsoft Excel 2016), analysed and interpreted accordingly.

1.6 Thesis Outline

The thesis is organized into five main chapters. Chapter one 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 two presents in detail about geology in the Air Piau, Kelantan found in other earlier research. Chapter three explains about the methodology that being used from the first step to the last step until get the result. Chapter four shows on whole results of study and also discussion on the result. The conclusion and recommendation from the research will be discussed in chapter five.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

The various theories of ore genesis explain how the various types of mineral deposits form within the Earth's crust. Ore genesis theories are dependent on the mineral or commodity. Ore genesis theories generally involve three components which are 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 physical or chemical phenomenon which encourage movement. Trapping is required to concentrate the metal via some chemical, physical or geological mechanism into a concentration which forms mineable ore. The biggest deposits are formed when the transport mechanism is efficient, the source is large, 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 two process which are 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 volcanic or plutonic rock. Internal processes can be classified into several types such as hydrothermal processes, magmatic processes and metamorphic processes (Evans, 1992).

i. Hydrothermal processes

These processes are the physicochemical phenomena and reactions caused by movement of hydrothermal waters within the crust, often because of magmatic intrusion tectonic upheavals. The foundations of hydrothermal processes are the source-transport-trap mechanism. Sources of hydrothermal solutions include seawater and meteor 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 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 and occur because of solubility of the host mineral within nascent hydrothermal solutions in the source rocks, for examples carbonates (cerussite), sulphates (barite), mineral salt (halite) and phosphates (monazite and thorianite). 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 solution, generally as hydroxides but also by processes like chelation. These processes are especially well understood in gold metallogeny where various thiosulphate, chloride and other gold-carrying chemical complexes. Most of metals deposits formed by hydrothermal processes include sulphide minerals, indicating sulphur is an important metal-carrying complex (Barnes, 1979).

Sulphide deposition within the trap zone occurs when metal-carrying sulphate, sulphide 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 sulphide to sulphate, oxygen fugacity, exchange of metals between sulphide and chloride complexes.

ii. 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 off separation of ore minerals by fractional crystallization separates ore and non-ore minerals according to their crystallization temperature. As early crystallization 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. Sulphide 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 are the examples. In magmas, sulphides 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).

B. Surficial Processes

Table 2.1 show the processes that involve in surficial process. Surficial processes are the chemical and physical phenomena which cause concentration of ore material within the regolith, general by the action of the environment. This includes placer deposits, laterite deposits and residual or eluvial deposits. The physical processes of ore deposits formation 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
Sedimentary precipitates	Precipitation of particular elements in suitable sedimentary environments with or without the intervention of biological organism.
Mechanical accumulation	Concentration of heavy, durable minerals into placer deposits.

Volcanic exhalative	Exhalations of hydrothermal solutions at the surface usually under marine condition and generally producing stratiform ore bodies.
Residual processes	Leaching from rocks of soluble elements leaving concentrations of insoluble element in the remaining material.
Secondary of supergene enrichment	Leaching of valuable elements from the upper parts of mineral deposits and their precipitation at depth to produce higher concentration.

2.2 Gold Formation

Gold is formed in a wide variety of hydrothermal deposits, which may be eroded, and the gold concentrated by hydraulic processes in rivers and on the beaches and deposited as sedimentary placer deposits (*Emas Lanar).* In hydrothermal deposits, gold is most commonly associated with silver and base metals, copper, lead and zinc. Most of these deposits are quartz veins deposited from hydrothermal fluids in fault zones at 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 gold supply. They are grouped into main classes. Quartz pebble conglomerate or 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 platinium group of minerals (Ariffin, 1995).

Young placers consist of gold bearing gravel and sand, and their consolidated equivalents, deposited in alluvial, beach and fluvioglacial environments during the Late Cenozoic (Quaternary and Tertiary period). These were the deposits worked during the gold rushes. Gravity and hydraulic action concentrate gold and other heavy minerals at locations where the water velocity decreases markedly, such as on the inside of meanders, below rapids and falls, in the boulders, 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.

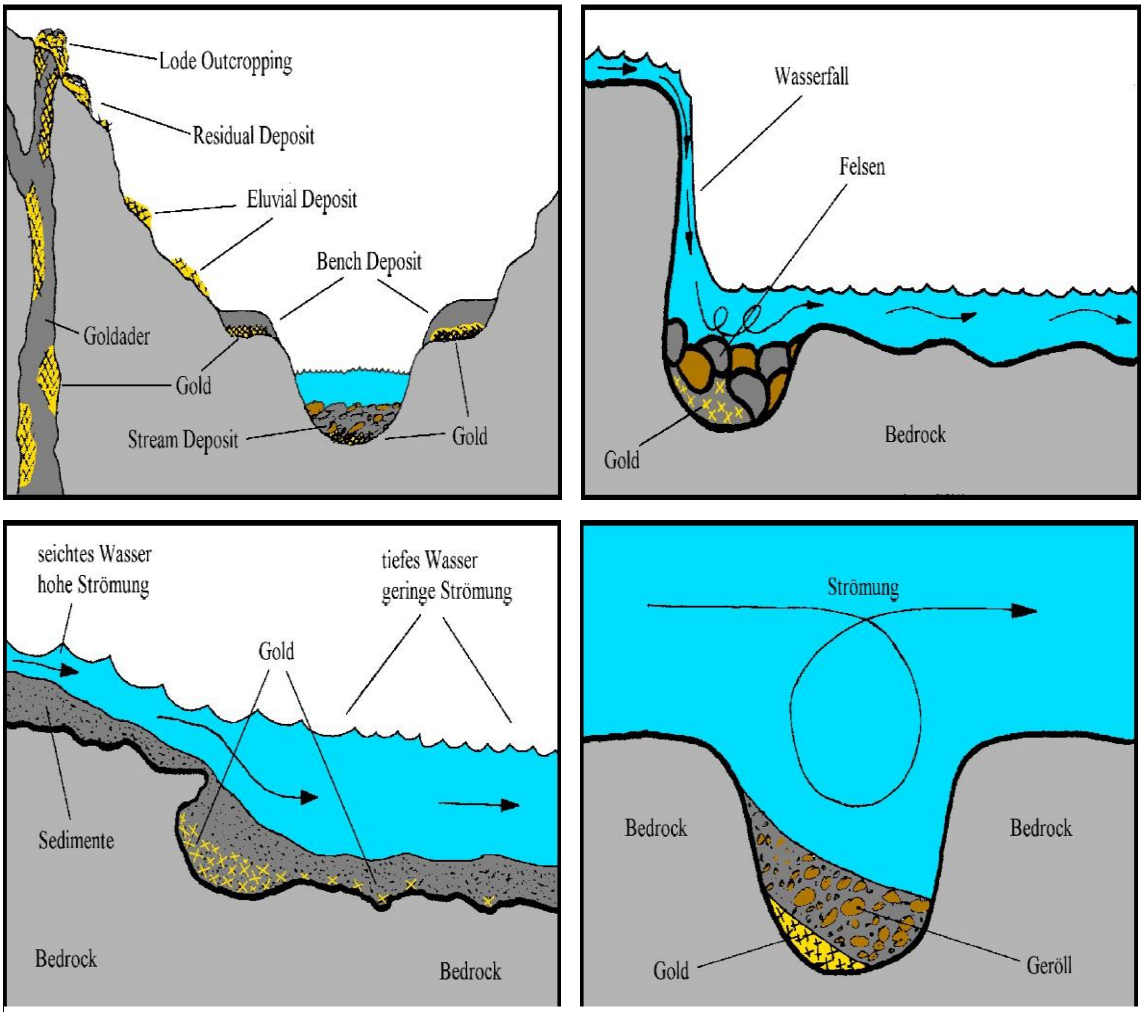

Figure 2.1: Young placer mineralogy (Ariffin, 1995)

Rich young placer deposits result from several cycles of erosion. Transport and deposition. In some placers, gold may be redistributed and re-concentrated by chemical migration and accretion 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 0.5g/t (Ariffin, 1995).

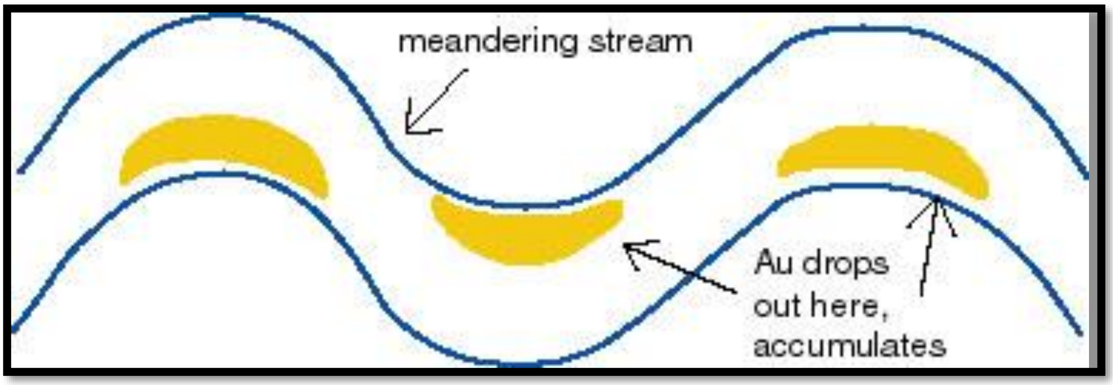

Figure 2.2: Insoluble of gold at a surface (Ariffin, 1995)

2.2.2 Lode Gold and Mesothermal Deposits

These are quartz lode deposits formed in fault and shear system at crustal level within and above the brittle-ductile transition zone, at depths of 3-12 km and temperatures from 200-400 ºC. 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 controversial but most current workers favour a metamorphogenic deformational origin, although some deposits may have had a magmatic influence in their genesis (Ariffin, 1995).

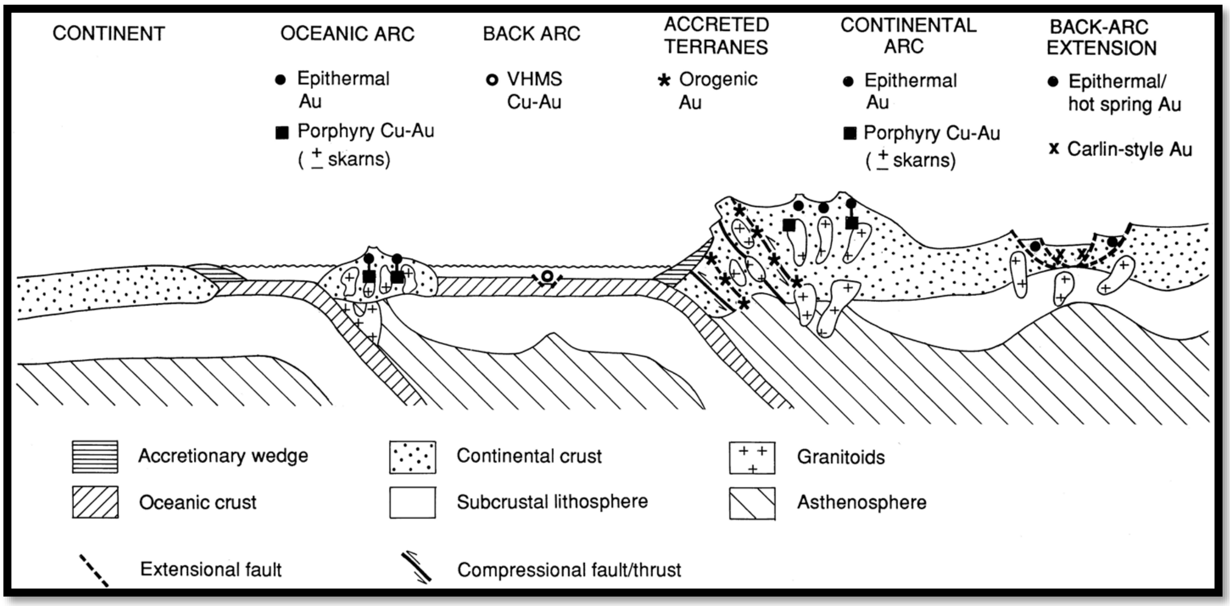

Figure 2.3: Tectonic setting of gold-rich epigenetic mineral deposits (Ariffin, 1995)

Figure 2.3 explains that epithermal veins and gold rich porphyry and skarn deposits, form in the shallow (< 5 km) and parts of both island and continental arcs 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 (Grove et al., 1998).

2.2.3 Mesothermal Deposits

Mesothermal deposits are the green lode gold deposits consists of gold-bearing quartz lodes found in Late Archean and Mesozoics greenstone belts. They are localised along or adjacent to major structural crustal breaks or suture zones, related to terrane collisional boundaries. The lodes are hosted in mafic and ultramafic volcanic rocks, banded iron formations, greywacke, and conglomerate, that have been metamorphosed to greenschist and locally amphibolite facies. Wallrock alteration is characterised 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; Metcalfe, 2000; Yeap, 1993; Teoh et al., 1987). Gold is widely distributed in Peninsular Malaysia [Figure 2.4] (Mohamad Sari, et al., 2005) 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 Penjom, Selinsing, Raub, and Ulu Sokor.

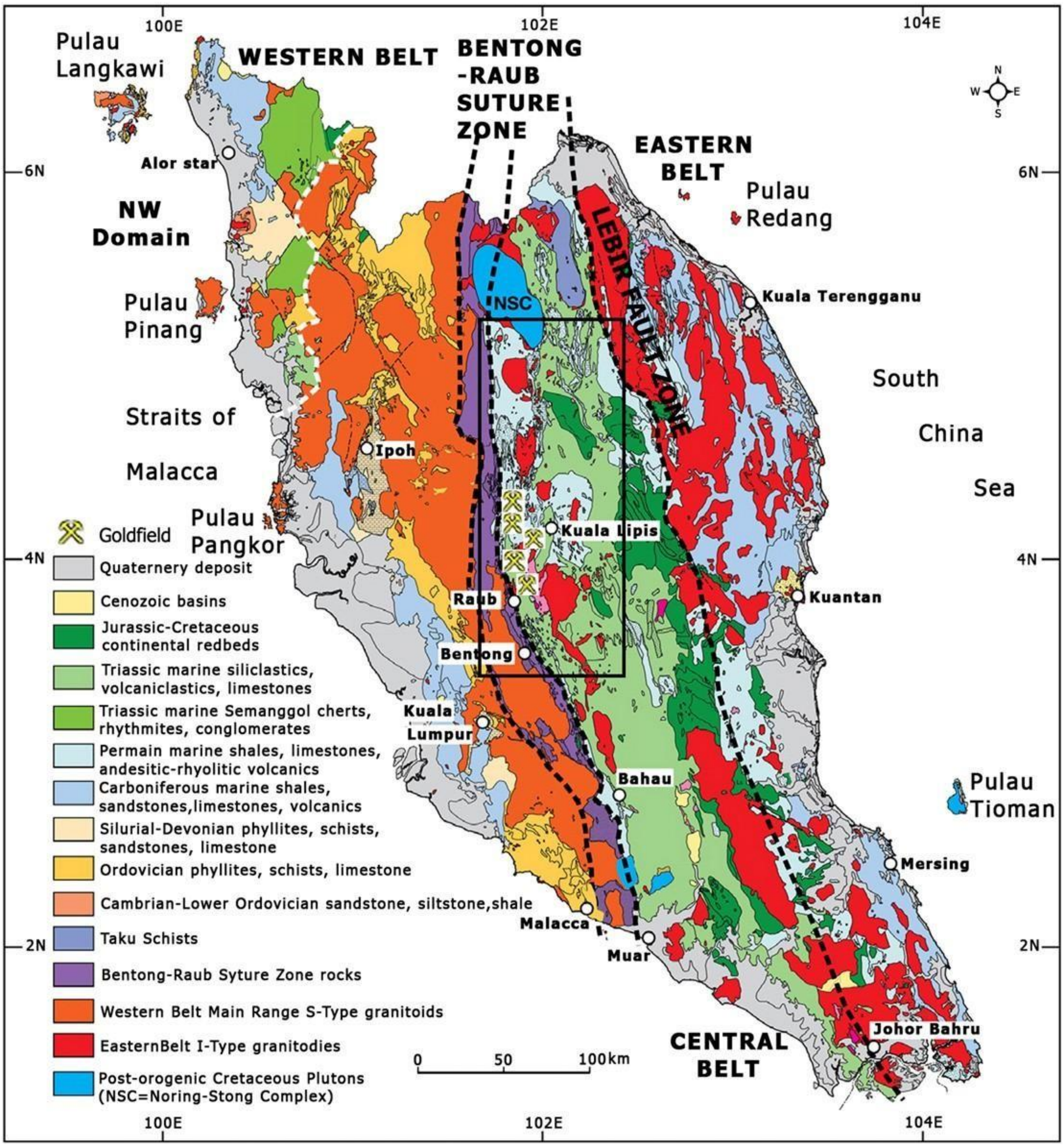

Figure 2.4: Simplified geological map of the peninsular Malaysia (After Tate et al., 2009)

Most of the gold deposits in the Central Gold Belt were classified as mesothermal lode types and orogenic deposits (Figure 2.5) 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 of gold (Ariffin, 2012). The orogenic gold deposits also shared the same characteristics of mesothermal lode (Goldfarb et al., 2001; Groves et al., 1988, 2003).

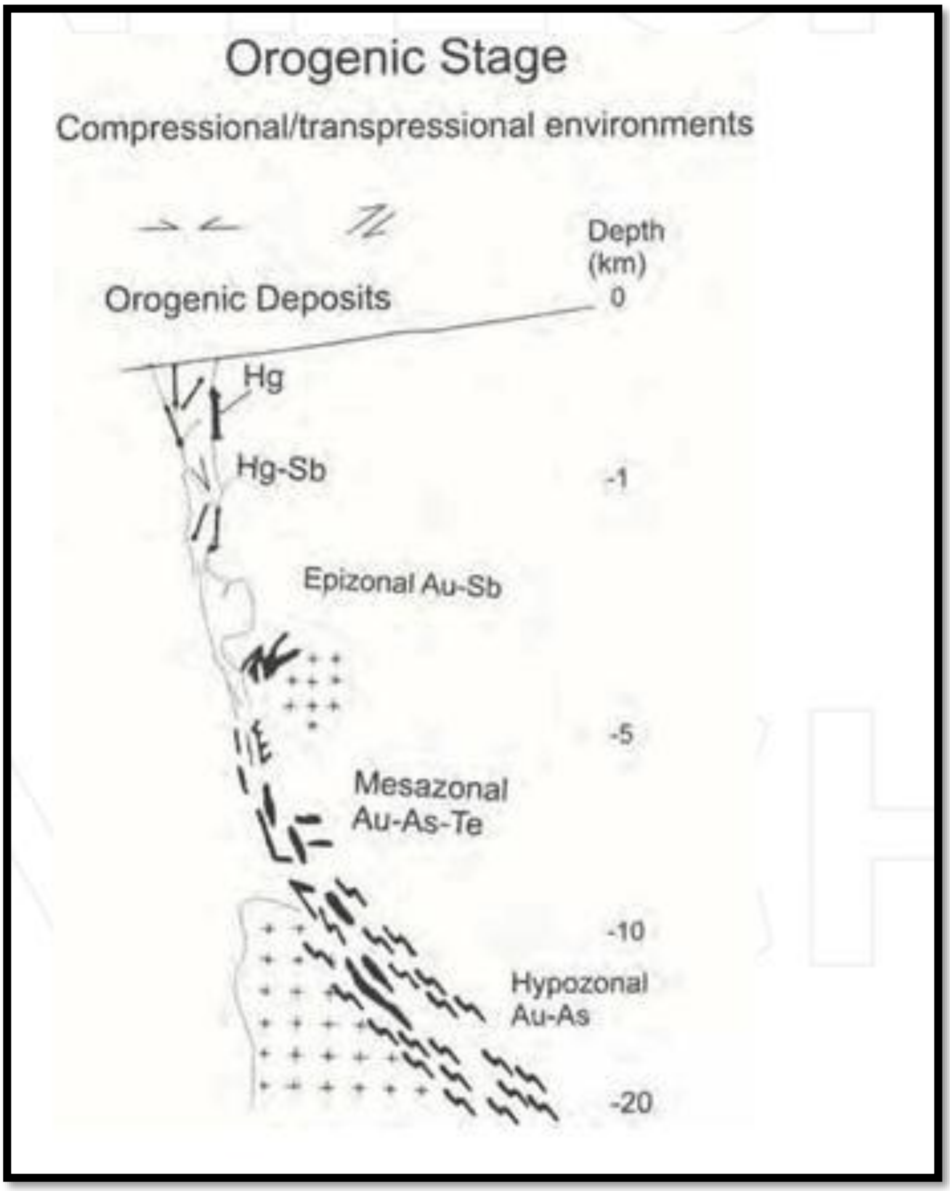

Figure 2.5: Schematic representation of crustal environments of orogenic gold deposits in term of depth of formation and structural setting within accreted Terrance (modified after Groves et al., 1998)

Metcalfe (2000, 2013a, 2013b) and Metcalfe & Allen, (2000) state that the Western Belt is part of the west Sibumasu 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 Sibumasu 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; Metcalfe, 2011).

Another suggestion has been made saying that the collision of Sibumasu-Indochina (Figure 2.6) 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 magmatism which lead 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).

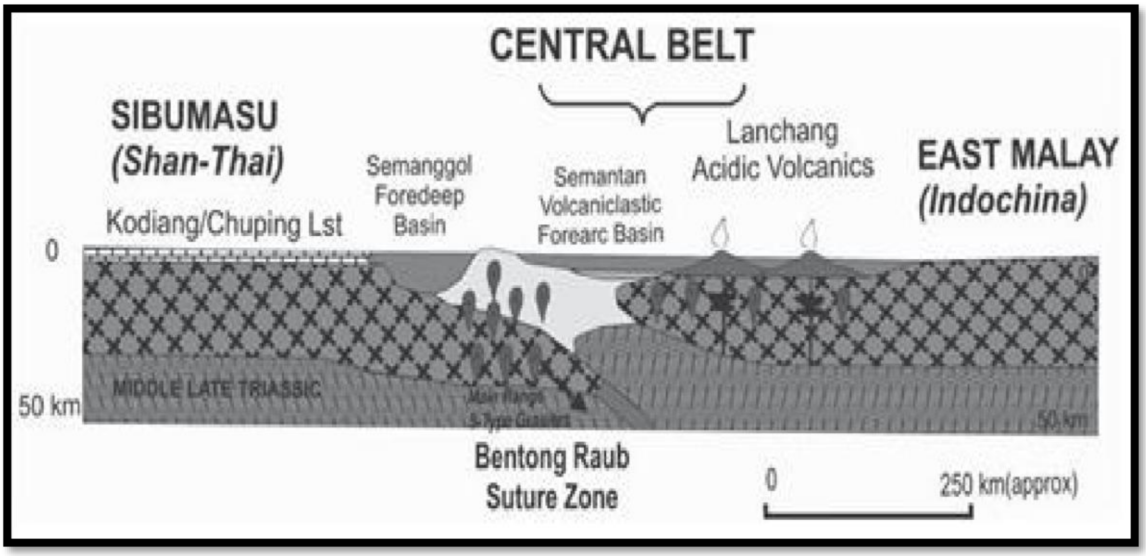

Figure 2.6: Model of Sibumasu and Indochina Collision (Ariffin, 2012)

The Western Belt comprises Early Palaeozoic continental margin sequences, Late Palaeozoic to Triassic platform carbonates, Triassic deep basinal clastic sequences and Jurassic to Cretaceous continental deposits (Makoundi et al., 2014). The Permian to Triassic Semanggol Formation comprises of conglomerate and turbidite sandstone, and bedded chert (Makoundi et al., 2014). The Silurian to Devonian Sungai–Patani. Formation composed of black-shale bearing sequences (Makoundi et al., 2014). Jurassic to Cretaceous Salong beds mainly consist of conglomerates (Makoundi et al., 2014). The dominant magmatic rocks are in the Main Range at the age of Late Triassic to earliest Jurassic S-type granitoids (Metcalfe, 2011).

A variety of depth of marine clastic sediments and limestone, with some felsic and volcaniclastics were undergone deposition during age of the Permian to Triassic. Then, they experienced low-grade metamorphism which later built up the Central Belt (Leman, 1994; Sone et al., 2004). The granitoids in the Eastern belt comprises of Biotite granite, K-feldspar, and tonalite (Makoundi et al., 2014) and were generated by subduction of the Paleo-Tethys beneath Indochina–East Malaya (Sone &Metcalfe, 2008).

The Bentong–Raub Suture Zone represents the boundary between the Western Belt of Sibumasu Terrane and the Central Belt and Eastern Belt of Sukhothai Arc (Metcalfe, 2013b). This suture contains limestone, conglomerate, turbidite, volcanic and volcaniclastic rocks, sandstone and serpentine (Metcalfe, 2000). After a few suggestions on model of this suture, the model which suggested that subduction of the Paleo-Tethys oceanic crust beneath the Sukhothai Arc staring at the Permian and that the collision between Sibumasu and the Sukhothai Arc happened during the Triassic is accepted (Metcalfe, 2011).

2.4 Regional Geology of Kelantan

The regional geology of Kelantan was divided into three zones which are West, Central and East Zone (Goh et Al., 2006). The Central Zone mainly consists of sedimentary, metasedimentary rocks and granitic intrusive with a north-south trend, essentially a northern continuation of the regional geology of north Pahang. In west and central Kelantan, the belts continue northward into south Thailand but in the east the Boundary Range granite is overlain by the coastal alluvial flat of Sungai Kelantan.

MacDonald (1967) stated that the oldest rocks found in Kelantan are at the age of Lower Palaeozoic whilst amphibolite and serpentines are being rarely discovered. The Permian volcanic-sedimentary rocks occur in the eastern side of Kelantan, while pre-Triassic Taku Schist occurs in central-north of the state, and Triassic rocks are mainly distributed to central and south Kelantan (Li et., al, 2014). The youngest rock that has been reported is at the age of Jurassic-Cretaceous. They overlie at the boundary between three states which are Pahang, Terengganu, and Kelantan. They are also extended in the west side of the Gunung Perlis and Gunung Pemumpu. The geological map for the state of Kelantan is as shown in Figure 2.7.

Kelantan Gold district has regional-scale structures dominantly in the geometry of N-S and NW–SE trending faults, such as the fault zone of Lebir with huge numbers of subsidiary NE–SW trending faults (Li et al., 2014).

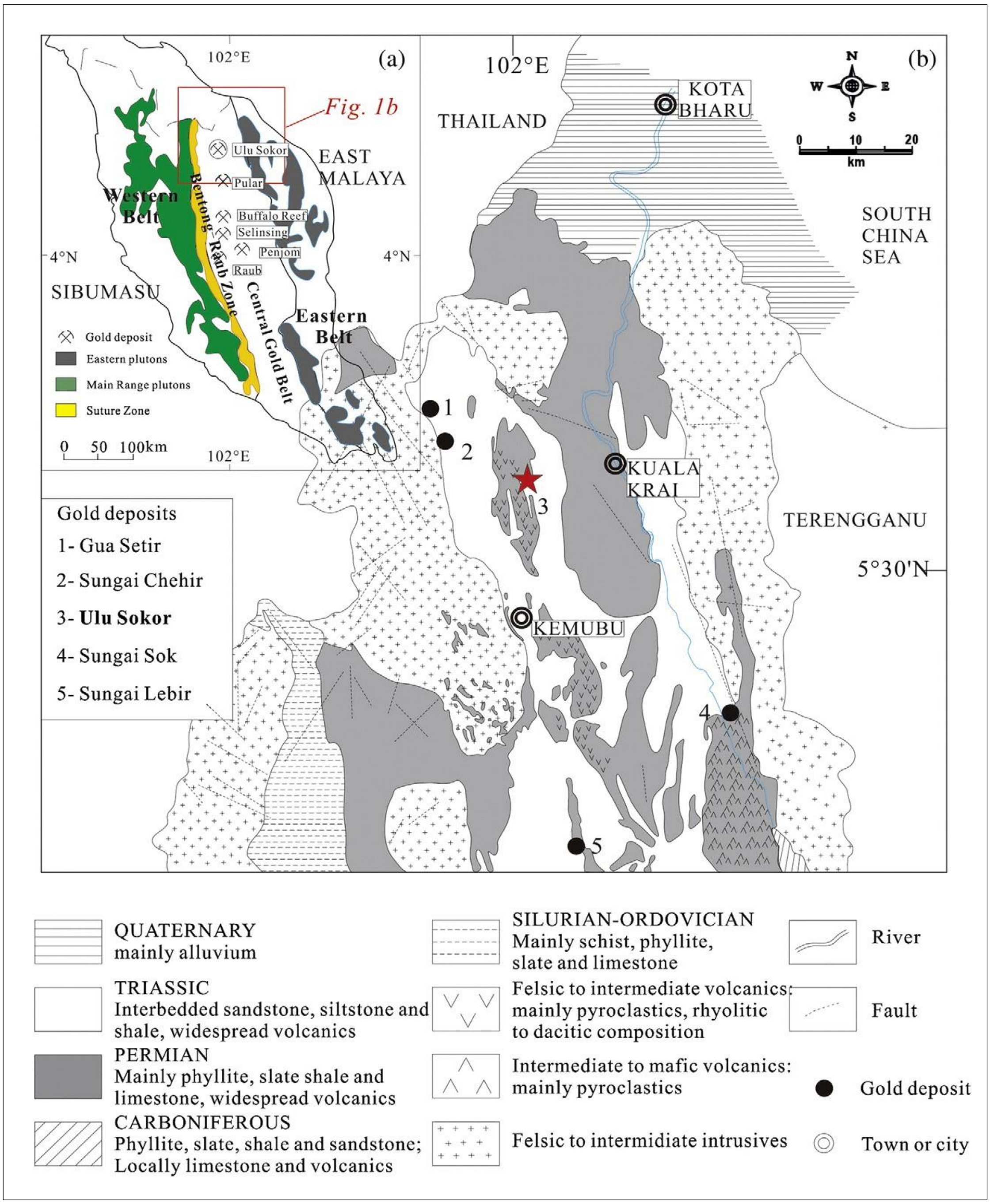

Figure 2.7: Simplified geologic map of the Malay Peninsula (a) and the Northern Kelantan (b) showing the location of the Air Piau and other gold deposits (modified after Heng et al., 2006 and Ariffin and Hewson, 2007. Li et al., 2014)

2.5 Potential of Gold in Kelantan

Gold mineralization in Kelantan was discussed in detail by Goh et al. (2006); Chu & Singh (1986), Chu (1983 & 1980). Most of the gold mines in Kelantan are working on placer deposits and they contribute approximately 10% of the annual gold production of Malaysia (Ariffin, 2012). Goh et al (2006) and Ariffin (2012) stated that mineralization of gold in Kelantan is highly concentrated in the central part of the state. The central part is bounded by 3 boundaries; Kemahang granite in the north, Boundry Range granite in the east, and Stong Igneous Complex and Seting Granite on the west.

Ulu Sokor is the most vital gold deposit in the state of Kelantan, which has been mined for more than 100 years as a placer deposit (Li et al., 2015). The type of deposit at Ulu Sokor is volcanic-hosted massive sulphide deposit and the formation of gold is during volcanic activity in the Permian to Triassic (Heng et al., 2006). Heng et al (2006), Li et al (2010, 2011), Rishworth (1974), and MacDonald (1967) has discussed the geology of the Central Part of Kelantan. They agreed that felsic to intermediate volcanic rocks has dominated the Kelantan gold district. Li et al (2010, 2011) suggested that these volcaniclastics are dominated by agglomerate, tuff breccia, tuff and pyroclastic with rhyolitic to dacitic lava,

Ariffin (2012), and Ariffin & Hewson (2007) have recorded that the oldest rocks reported in the Ulu Sokor deposit are of the meta-sedimentary rocks including rhyolitic crystal tuff, shale, phyllite, limestone and slate which are at the age of Permian whilst sedimentary rocks mainly consist of interbedded sandstone, siltstone and shale with lesser amounts of volcaniclastics are at the age of Triassic. Ulu Sokor mining area is mostly covered by the phyllite. The main component of rhyolitic crystal tuff is silica with medium- grained aggregates, feldspar, tuff breccias and agglomerate (Li et al., 2010, 2011).

Batcher (1994), and Chu & Singh (1986) suggests that primary gold mineralization in Kelantan is associated with massive sulphide bodies, pyritiferous and carbonaceous meta-sediments, Ag-Au quartz veins, skarn-type mineralization, and sulphide-bearing volcanic and volcaniclastic rocks. Oxidised bodies show a satisfied gold enrichment by displaying a higher gold tenor than primary sulphides. Most of the gold in the primary sulphides is locked in pyrite. Hard rock gold mineralization normally in association with large quartz grains (Yeap, 1993), present of quartz stock works, and volcanogenic exhalative sulphides within a shear zone system (Ariffin and Hewson, 2007).

Gold mineralization also related to the intrusive rocks and may occur in shear zones in granite (Schroeder & Cameron, 1996) and not really significant (Batchelor, 1994; Chu 1983; Chu et al., 1980). Quartz veins that are developed along the shear zones crosscutting the granitoid. can be seen in Katok Batu Mine, Pulai and Batu Melintang (Goh et al., 2006).

2.6 Type of Gold Deposit

Goh et al (2006) has discussed the nature and origin of gold mineralization in Kelantan. Gold mineralization is identified in three types of deposits which are volcanogenic massive sulphide, skarns and hydrothermal quartz vein deposits. Goh et al (2006) then classified the types of hydrothermal quartz veins into six types as can be observed Figure 2.8.