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UNIVERSITI TEKNOLOGI PETRONAS

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by

HISSEIN ADOUM ALKHALI

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HISSEIN ADOUM ALKHALI

A Thesis

Submitted to the Postgraduate Studies Programme

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MASTER OF SCIENCE

GEOSCIENCE AND PETROLEUM ENGINEERING

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DECLARATION OF THESIS

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I HISSEIN ADOUM ALKHALI

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DEDICATION

I dedicate this thesis to my beloved family members, particularly to:

My wonderful mother, Mahdiyah Hissein the most supportive person on the planet! Who always believed that I'm capable of achieving whatever I want in life.

My father, who taught me the meaning of life, values and who always emphasized the importance of education.

My older brother, Mohammed (Abo-Abduallah), who has been my role model for hard work and persistence, and who instilled in me the inspiration to set high goals and the confidence to achieve them.

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ABSTRACT

The clastic rocks outcropping at Seri Iskandar are part of the Paleozoic sedimentary deposits in the Kinta Valley and little is known about these Paleozoic clastic deposits.

Over the years, some efforts have been made to evaluate the hydrocarbon potential of pre-Tertiary deposits and initial observation of Paleozoic sedimentary sequences in the Kinta Valley suggests the presence of elements of the Paleozoic hydrocarbon system.

Yet to date, no study has been undertaken on the pre-Tertiary rocks in the western part of Peninsular Malaysia to verify if the Paleozoic clastics or its time-equivalent could be part of a hydrocarbon system.

This is the first detailed geological study of the clastic deposits in the Seri Iskandar area and is intends to document these clastic deposits, provide sedimentology and petrology analysis and assess the possibility that these clastic deposits could be an analog of a potential hydrocarbon reservoir.

Four outcrops (with a total thickness of 785m) consisting of alternating beds of sandstone, siltstone, mudstone and thinly interbedded sandstones, siltstones and mudstones were studied. Some beds have sub-vertical dips and are locally folded. Sedimentary structures recognized in the beds include load cast, graded bedding, lamination, burrow tracks and slumps. No fossils have been found within these deposits. It was most likely deposited on the lower part of a marine slope.

The sandstones of Seri Iskandar are dominantly composed of cemented quartz with subordinate feldspar and minor amounts of black grains of heavy minerals. Results of the sedimentologic and petrographic studies indicate that these sandstones are considered compositionally and texturally mature and underwent different types of

diagenetic processes including compaction, cementation, fracture infill and dissolution and precipitation.

A comparative study shows that the clastic deposits of Seri Iskandar are part of the Kati Formation and have been assigned as Carboniferous-Permian age.

Investigations on the porosity and permeability from thin sections pairs with petrophysical measurement of surface core samples (from poro-perm) demonstrate the existence of a potentially poor reservoir and does not qualify as an analog of a potential hydrocarbon reservoir. The sandstones would not serve as a possible reservoir for the potential Paleozoic hydrocarbon play.

ABSTRAK

Singkapan batuan klastik di sekitar Bandar Seri Iskandar merupakan sebahagian daripada deposit sedimen Paleozoik di Lembah Kinta dan pengetahun berkenaan deposit klastik Paleozoik ini adalah terhad.

Beberapa tahun kebelakangan, usaha telah dijalankan untuk menilai potensi hidrokarbon deposit pra- Tertiari dan pemerhatian awal jujukan sedimen Paleozoic di sekitar Lembah Kinta menunjukkan kewujudan unsur-unsur sistem hidrokarbon Paleozoik .

Namun sehingga kini, tiada kajian yang dijalankan ke atas batuan pra-Tertiari di kawasan barat Semenanjung Malaysia untuk mengesahkan bahawa batuan klastik Paleozoik atau batuan setara usianya adalah sebahagian daripada sistem hidrokarbon.

Ini adalah kajian geologi pertama deposit klastik di sekitar kawasan Seri Iskandar dan bertujuan mendokumentasikan deposit klastik ini, menyediakan sedimentologi dan analisis petrologi dan menilai kebarangkalian jika deposit klastik ini berpotensi sebagai analog takungan hidrokarbon. Kaedah penyiasatan merangkumi kerja lapangan dan analisis makmal. Empat singkapan terdiri daripada selanglapis lapisan batu pasir, batu lodak, batu lumpur dan batu pasir nipis, batu lodak dan batu lumpur telah dikaji.

Sesetengah lapisan mempunyai kemiringan separa menegak dan struktur-struktur sedimen yang dapat diperhatikan ialah kas, lapisan bergred, laminasi, kesan korekan dan nendatan. Tiada fosil ditemui dalam deposit ini, berkemungkinan besar disimpan di bahagian bawah cerun laut.

Batu pasir dominan yang tersingkap di kawasan Seri Iskandar terdiri daripada kuarza tersimen dengan sebilangan feldspar dan sejumlah kecil butiran hitam mineral berat.

Keputusan kajian sedimentologi dan petrografi menunjukkan bahawa batu pasir dikategorikan sebagai matang serta telah mengalami pelbagai proses diagenetik berdasarkan kandungan dan teksturnya termasuk proses pemadatan, penyimenan, pengisian,retakan,pelarutan dan pemendapan.

Satu kajian perbandingan menunjukkan bahawa deposit klastik Seri Iskandar adalah sebahagian daripada Formasi Kati dan telah ditafsirkan berumur Karbon-Permian.

Hasil kajian keliangan dan kebolehtelapan daripada keratan nipis beserta ukuran petrofisik daripada sampel teras permukaan(dari poro-perm) menunjukkan kewujudan takungan berpotensi rendah dan tidak layak dikategorikan sebagai analog takungan hidrokarbon. Ini u kerana,batu pasir tidak boleh bertindak sebagai takungan sistem hidrokarbon Paleozoik.

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CHAPTER 1

INTRODUCTION

1.1 Background

Paleozoic rocks in Peninsula Malaysia are mostly marine and cover over about 25% of Peninsula. There are forty-two formations mentioned in the stratigraphic lexicon of Malaysia (Foo, 1983; Tjia, 1999a; Lee et al., 2004; Lee, 2009). These Paleozoic deposits are exposed in several locations in Peninsular Malaysia and they are widespread in the western part of the Peninsular (Figure 1.1). Some of them are exposed in the Kinta Valley and in the surrounding district of Kuala Kangsar in central Perak.

Kinta Valley is an elongated alluvial plain, situated up to 43 meters above sea level. It is underlain mainly by carbonates which are widespread and interbedded within the carbonates are rare clastic sequences (Fontaine & Amnan, 1995). In general, two Paleozoic Formations were mapped in the Kinta Valley and Kuala Kangsar area, namely the Silurian Kinta Limestone in the east and the Carboniferous Clastic Kati Formation to the west (Gobbett & Hutchinson 1973; Foo, 1983, 1990). The Paleozoic clastic sequences crop out in Sungai Siput and Kuala Kangsar in the northwestern part of the Kinta Valley. These rocks extend southward to Tapah, Teluk-Intan, Bukit Tunggal and Lumut (southern part of the Kinta Valley). They also crop out along the northeastern part of the Kinta Valley in Siputeh, Parit, Tanjung Tualang and at Seri Iskandar (near Tronoh) in particular, where there are thick sequences of sandstone with minor interbeds of siltstone and mudstone.

In the near future, there will be a need to augment oil production from maturing fields, and to add oil and gas reserves to meet local energy requirements. In response, there is a need to know more about older formations and possibly to explore for new plays.

Hydrocarbon exploration activities in Peninsular Malaysia focused mainly on the Tertiary Formations and despite the fact that, hydrocarbon reserves have yet to be discovered in the pre-Tertiary formations of Peninsular Malaysia, new hydrocarbon plays have recently begun to gain significant attention and some exploration efforts have targeted the Paleozoic system in Malaysia, mainly as an evaluation for its hydrocarbon potential.

Initial observation of the Paleozoic sedimentary sequences in the Kinta Valley suggests the possible presence of a Paleozoic hydrocarbon system with source rocks, potential reservoirs and seals. Moreover, there are very few wells which had penetrations into the Paleozoic deposits and the potential for the existence of reservoirs at this level is poorly understood. Although a Paleozoic hydrocarbon system is still speculative (?), the possibility cannot be ruled out (Tjia, 1999b; Abd Kadir et al., 2009; Pierson et al., 2009). As such, it would be interesting to document the clastic deposits of Seri Iskandar, determine its sedimentological and petrographic properties and find out if the thick sequences of sandstones around Seri Iskandar have potential as reservoir rocks.

In this study, we have taken the first steps toward understanding the clastic rocks outcropping at Seri Iskandar. The outcomes of this study will reduce to some degree the uncertainties on elements of the Paleozoic hydrocarbon plays and will benefit for future work on Paleozoic hydrocarbon plays.

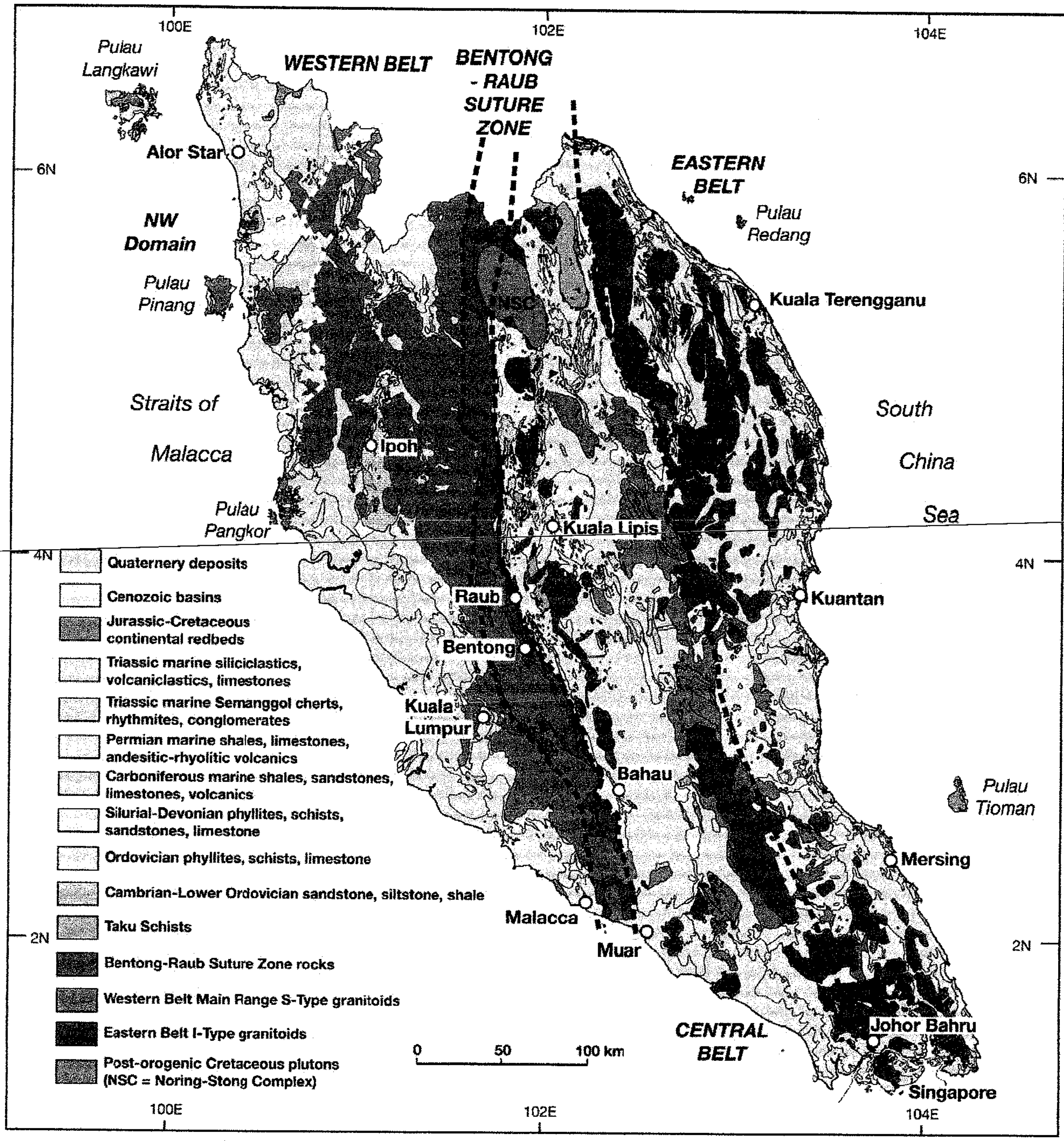

Figure 1.1: Simplified geological map of Peninsular Malaysia after Tate et al. (2008), from Metcalfe (2013).

1.2 The Study Area

The study focused on isolated outcrops exposed at Seri Iskandar, in the Tronoh area. It is located in the south-western part of the Kinta Valley, and is almost 30km south of the Perak state capital Ipoh. Four main outcrops were recognized and studied in detail. These outcrops have been selected because they were fresh and provided good exposures of the various clastic rocks. The study area is bounded by coordinates 100°56'0" and 100°57'30"E, 4°22' 0" and 4°23'0"N (Figure 1.2).

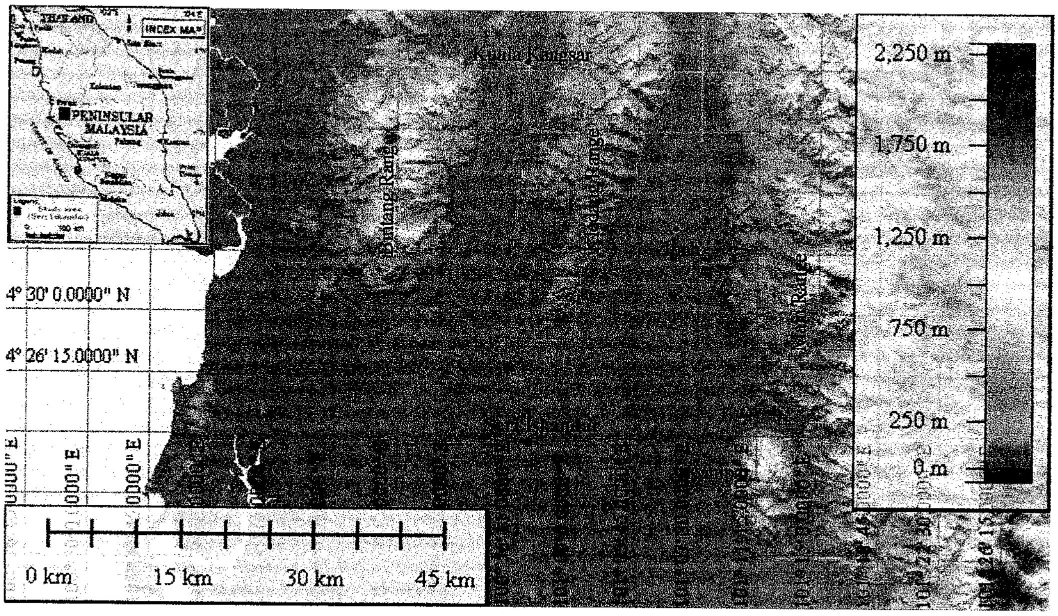

Figure 1.2: Digital elevation model (DEM) map of the study area showing the location of the Seri Iskandar.

1.3 Previous Studies

Limited geological work was carried out in the Kinta Valley and the surrounding areas to investigate the Paleozoic clastic sequence. The geology of this region was first described and mapped by Scrivenor (1913) and one of the best early descriptions of rocks of the Kinta Valley area are those of Scrivenor and Jones (1919), in particular the Dindings area (currently known as Manjung) where they identified three dominant geological units (Ingham & Bradford, 1960;Wong, 1991):

1) The Carboniferous-Permian calcareous series
2) The Triassic arenaceous series
3) The Mesozoic granites

Savage (1937) conducted investigations in Sungai Siput and the adjacent areas (northern part of the Kinta Valley) and recognized the existence of five distinct stratigraphic units:

1) Limestone and associated rocks
2) Quartzite and associated rocks
3) Quartz-porphyry (foliated and not foliated)
4) Granite and Allied rocks
5) Alluvium

Ingham (1938) examined the rocks exposed in Tapah and Telok Anson currently known as the Teluk-Intan area (southern part of Kinta Valley), the deposits to which he referred to as:

1) Limestone and associated rocks
2) Quartzite and associated rocks
3) Granite and Allied rocks
4) Alluvium

Ingham and Bradford (1960) extended the work over to the northeastern part of the Kinta Valley. According to Ingham and Bradford (1960), rocks in the Kinta Valley area can be divided into three main series:

1) The calcareous series
2) The granites and allied rocks
3) The arenaceous series

The notable effort by Ingham and Bradford (1960) is certainly one of the most interesting and highly cited works on the geology of the Kinta Valley.

Foo (1990) reported the Paleozoic and Mesozoic exposures of Kuala Kangsar and Taiping area (northern part of Kinta Valley). The Mesozoic rocks are present mainly in Taiping (the Triassic Semanggol Formation), while the Paleozoic rocks are well represented in Kuala Kangsar by three sedimentary formations:

1) The Pondok Marbles
2) The Kati Beds
3) The Salak Baharu Beds

Wong (1991) conducted investigations in the Lumut and Teluk-Intan area (southern part of Kinta Valley) and recognized three sedimentary successions with their metamorphosed equivalents, namely:

1) The Kati Beds (the arenaceous and argillaceous series)
2) The Tualang Limestone (part of Kinta Valley Silurian-Permian limestones)
3) The Gelubi Schists.

These units are believed to be contemporaneous and are classified as Carboniferous to Permian in age. The Tualang Limestone and Gelubi Schists make up the previously so-called "the calcareous series".

Foo (1990) and Wong (1991) stated that Ingham (1938) and Ingham and Bradford (1960) wrote of the same Formation (arenaceous series) in the west and southwest of the Kinta Valley area. This Kati Beds (Formation) extend southwards to the Seri Iskandar area. These studies will be discussed at greater length in the next chapter.

1.4 Problem Statement

The clastic rocks outcropping at Seri Iskandar are part of the Paleozoic sedimentary deposits in the Kinta Valley and not much is known about this Paleozoic clastic deposits. Hydrocarbon exploration activities in Peninsular Malaysia focused mainly on the Tertiary Formations and despite the fact that, hydrocarbon reserves have yet to be discovered in the pre-Tertiary formations of Peninsular Malaysia, new hydrocarbon plays have recently begun to gain significant attention.

Over the years, some efforts have been made to evaluate the hydrocarbon potential of pre-Tertiary deposits and initial observation of the Paleozoic sedimentary sequences in the Kinta Valley suggests the presence of elements of a Paleozoic petroleum system (Tjia, 1999b; Pierson et al., 2009). Yet to date, no study has been undertaken on the pre-Tertiary rocks in the western part of Peninsular Malaysia to document the Paleozoic clastic deposits and verify if these Paleozoic clastics or its time-equivalent could be part of a possible hydrocarbon system.

As such, this study intends to document these Paleozoic clastic deposits of Seri Iskandar, focused on its sedimentology and petrology to find out if the thick sequences of sandstones around Seri Iskandar have reservoir potential.

In short, this research sheds new light on one of the elements of Paleozoic hydrocarbon play. Moreover, it may open up new opportunities and lead to possibilities for discoveries in places never thought possible. The insights gained from this study would be useful to better understanding of the Paleozoic clastic sequences and the results of reservoir assessment provide a substantial foundation for further investigation and exploration of Paleozoic clastic sequences.

1.5 Methodology

In this field-oriented research, the interpretation of the Paleozoic clastic sequence of Seri Iskandar is based mainly on data from outcrops. Field work and laboratory analysis collectively include an interdisciplinary study of sedimentology and petrography. The investigation methods were divided into:

1) **Field work:**

Fieldwork involved identification of lithologies and measurement of the thicknesses of the beds. Sampling and coring of samples were carried out during the field study.

2) **Laboratory work:**

The samples from the field were made into thin sections and also for laboratory tests and analysis. This included porosity and permeability measurement, grain size analysis and petrophysical studies. These data were analyzed by a variety of techniques to achieve the objectives of the study in four scales of information:

1) Lithologs (stratigraphic column)
2) Microscopic thin sections
3) Hand samples
4) Surface core plugs samples

1.6 Objectives

The objectives of this research are as follow:

1) To document the Paleozoic clastic deposits of Seri Iskandar.
2) To determine the sedimentology and petrology of Paleozoic clastic.
3) To assess the clastic deposits of Seri Iskandar as potential hydrocarbon reservoir rocks.

1.7 Thesis Outline

This thesis is structured into the following chapters:

- Chapter 1 covers the background, problem statement, objectives of the study and an overview of the previous studies carried out in the area.
- Chapter 2 presents a review of related literature on the geological setting of the area, the general and fundamental concept of geology applicable in this research, and a review of Paleozoic hydrocarbon plays in Peninsular Malaysia.
- Chapter 3 covers the material and methods that were used in this research.
- Chapter 4 explains the results of the field observation, laboratory analyses, structural observation and discussions on the reservoir potential of sandstone units. Included in this chapter is a detailed description of the outcrops.
- Chapter 5 includes the conclusion and recommendation for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A critical review and evaluation of all the available and relevant literature of previous geologic studies along with regional geology overview are considered to be the most basic step towards understanding the geology of a particular study area. In addition, the subject of this research is a field-oriented study of the Paleozoic clastic successions at Seri Iskandar. The purpose of this chapter is thus, to provide an overview of the geological setting and briefly elaborate on some basic geological concepts and techniques which are applicable in this research.

In order to investigate and evaluate the role of Paleozoic clastic sequence in a possible hydrocarbon play, related literature on" Paleozoic hydrocarbon plays in Peninsular Malaysia" have to be reviewed.

The insights gained from these literature reviews provide a coherent background and context for the research problem statement and contribute significantly to a better understanding of the surface geology of the area. Furthermore, it has also played a pivotal role in this research as a guide conducting the field investigation and laboratory analysis.

This chapter is divided into three sections, each of which critically reviews literature related to the geology of the study area:

1) Regional overview and previous work.
2) Paleozoic hydrocarbon plays in Peninsular Malaysia.
3) Fundamental concept of geology which is applicable in this study.

2.2 Regional Overview

Peninsular Malaysia is a part of Sundaland, a biogeographical region of Southeast Asia. In the basis of tectonostratigraphic terrains, Peninsular Malaysia is composed of two tectonic entities, the western part is belonging to Sibumasu Block (Gondwana fragment) and the eastern part (larger part) is belonging to East Malaya Block (Indochina Block) (Figure 2.1). The suture line for this collision known as Raub-Bentong Suture (Triassic time) which forms a boundary between these two continental crustal blocks.

Moreover, the different types of volcanic rock found in East Malaya Block and Sibumasu Block become the important evidence to explain their regional tectonic setting (Hutchison, 1994, 2009; Tjia, 1999a; Cocks et al., 2005; Barber & Crow, 2005; Lee, 2009; Metcalfe, 2000, 2002, 2006, 2011; Cmakoundi, 2012; Ridd, 2012).

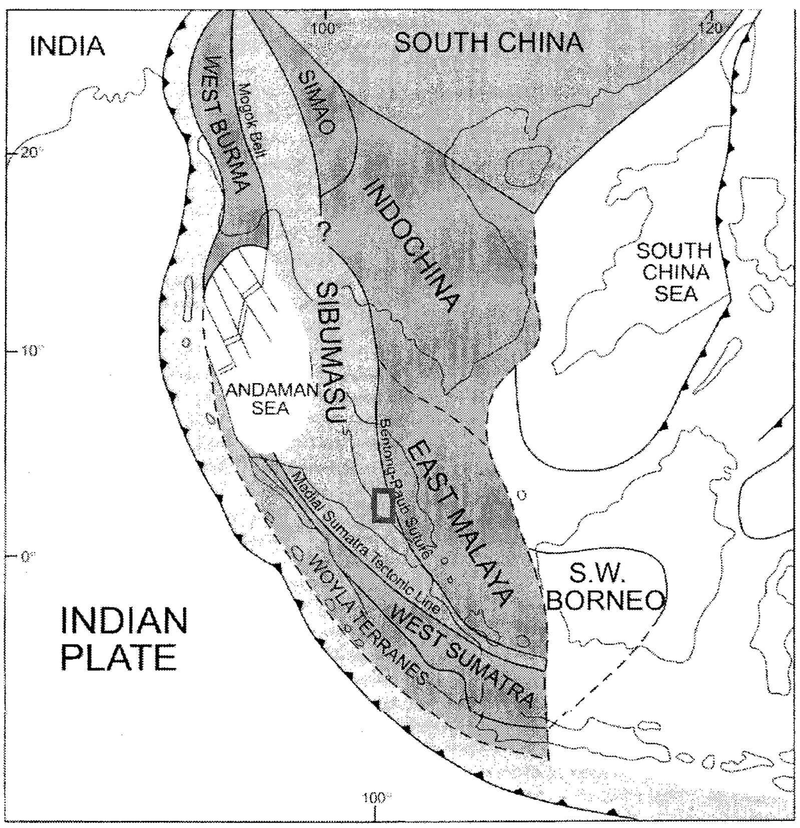

Figure 2.1: Distribution of continental blocks and suture zones in Southeast Asia region, from Metcalfe (1988) and Barber & Crow (2005). The red square represents the study area in the western part of Peninsular Malaysia.

2.2.1 Pre-Tertiary evolution of Southeast Asia and Peninsular Malaysia

The pre-Tertiary tectonic evolution of Southeast Asia formed mainly from the progressive suturing of the allochtonous continental blocks that rifted from Gondwanaland and migrated northward during Paleozoic and Mesozoic time, and in the Early to Late Cretaceous all these continental blocks were accreted (amalgamated) to form the proto-Southeast Asia continent (Metcalfe, 1984,1988,1998). These four major independent tectonic blocks include: Sibumasu Block, the East Malaya, Indochina and southwest Borneo.

In the Devonian, the Indochina block which includes the eastern part of Peninsular Malaysia (East Malaya) rifted and separated from the northeast part of Gondwanaland, ~~resulting in the opening of the~~ Paleo-Tethy Ocean. In the Late Devonian, driven by the expansion of Palaeo-Tethys the Indochina block moved northwards, to collide and amalgamate with the South China Block in the Early Carboniferous forming Cathaysialand (Barber & Crow, 2005; Metcalfe, 1996, 1998, 2000, 2005, 2011; Ridd, 2012). The Indochina block is characterized by a Permian flora and fauna (Barber & Crow, 2005).

Sibumasu was part of the Gondwanaland in Late Carboniferous-Early Permian. The Sibumasu block was rifted and separated from northern Gondwana and moved to the north to collide and amalgamate with Indochina (East Malaya) in Late Triassic time, this collision resulted in the closure of the Palaeo-Tethys Ocean and formation of the Bentong-Raub Suture. The Bentong-Raub suture zone forms the boundary between Sibumasu and the East Malaya block (Indochina) and represents the location of closure of the Palaeo-Tethys Ocean (Figures 2.2 and 2.3) (Metcalfe, 1988, 2000; Barber & Crow, 2005; Hutchison, 1993, 2009c; Ridd, 2012).

Sibumasu is characterized by pebbly mudstones, interpreted as glaciogenic diamictites or tillites (Barber & Crow, 2005). The best outcrops of pebbly mudstones in the Malay Peninsula are in the Phuket Group at Phanggna, and in the Langkawi Islands within the Singa Formation (Hutchison, 2009b, d).

In addition, the formation of the Bentong-Raub Suture Zone was probably contemporaneous with the emplacement of major faults that were conduits for most of the mineralising fluids. The Palaeo-Tethys subducted under the East Malaya-Indochina giving rise to Permo-Triassic volcanic rocks and I-type granites of the Sukhothai Zone (Sone & Metcalfe, 2008; Hutchison, 2009a).

The late episode of suturing in the Late Triassic evolved the evolution of crustal thickening resulting in the extensive emplacement of tin-bearing S-type granitic rocks, characterized by the Main Range in Peninsular Malaysia. The suturing and S-type granite emplacement occurred as an integral part of continental accretion and mountain building episode, known as the Indosinian Orogeny (Hutchison, 1989; Mitchell, 1992; Metcalfe, 2011; Ridd, 2012).

The central and eastern belt granites in Peninsular Malaysia are interpreted as the result of late orogenic extension. The late granite is also distributed throughout Peninsular Malaysia and surrounding South China Sea area and ophiolite, melange and accretion complexes occur along the margin of Sundaland in the late Cretaceous and Early Tertiary age (Metcalfe, 1998).

The Gondwana-affinity Sibumasu terrane has no Carboniferous and Permian volcanic rocks, and limestone is notably absent, except from the Carboniferous and begins to appear only in the Artinskian. This limestone is conformable with the pebbly-mudstone-bearing facies and upon the sandy facies of the Phuket Group, Singa Formation and Kubang Pasu Formation. It is known as the Ratburi Limestone in southern Thailand, and the Chuping Formation in northern Peninsular Malaysia (Hutchison, 2009b, d).

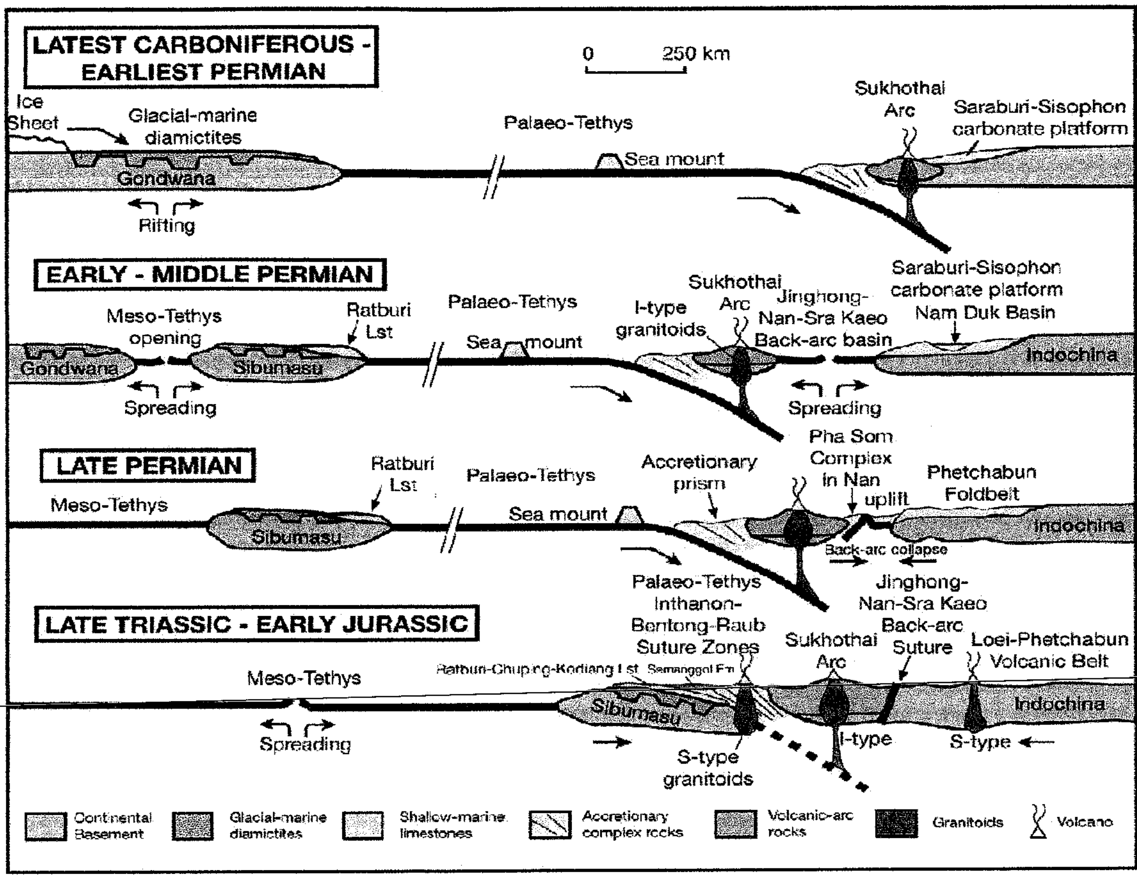

Figure 2.2: Cross-sections illustrating the tectonic evolution of Sundaland; Timing of rifting and collision of the Sibumasu and Indochina terranes and opening and closure of the Palaeo-Tethys Ocean and evolution of the Sukhothai Arc System during Late Carboniferous-Early Jurassic times (after Ueno & Hisada, 1999; Sone & Metcalfe, 2008).

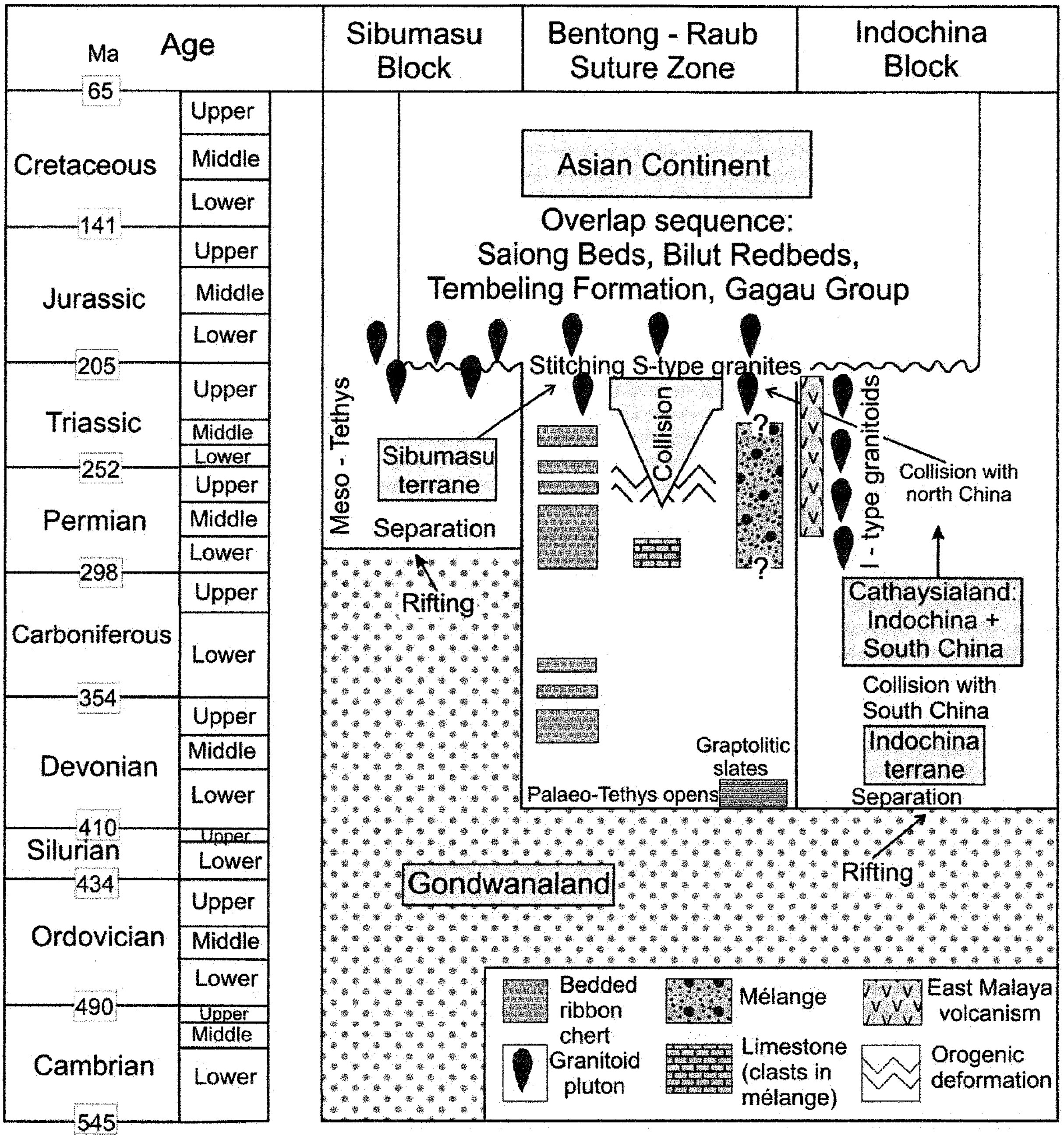

Figure 2.3: Timing of rifting and collision of the Sibumasu and Indochina teranes and opening and closure of the Palaeo-Tethys Ocean, based on Metcalfe (2000), modified by Hutchison (2009 b, d).

2.2.2 Stratigraphy, Structural and Tectonic Evolution

All the systems, ranging from the Cambrian to the Quaternary are represented in Peninsular Malaysia. Foo, (1983) recognized two sedimentation regimes based on the different periods of initial sedimentation; a western regime where a conformable Cambrian-Permian succession is evident, and an eastern regime where Carboniferous-Permian strata crop out in the central and eastern parts of the Peninsula. Marine sedimentation was continuous throughout the Paleozoic and Mesozoic and were interrupted by some intervals of non-marine deposits (land deposition) which occurred from Middle Cambrian to Late Triassic. However, because of the instability of the basin an apparent break in sedimentation occurs in the Paleozoic, Mesozoic and Cainozoic groups of rocks. In the Triassic-Jurassic time, rocks in this region underwent crustal deformation and extensive regional metamorphism and were intruded by large granitic plutons emplaced in a belts stretching from southern China over the peninsula to the islands of Bangka and Belitung (Indonesia).The deposition of continental sediments occurred sometime after granite emplacement (in the Jurassic-Cretaceous). A thermal event was recorded, at the Mesozoic-Cenozoic transition (might be related to the magma plume that produced the Malay, Penyu and West Natuna basins). At that time, Sundaland became tectonically stabilized, but wrench faulting up into Mid-Eocene has been radiometrically determined. Minor normal faulting was also recognized in the Tertiary deposits. While the Bengkalis segment of the suture (the southeast-ward extension of Bentong-Raub Suture) in the Central Sumatra Basin had been active until the Quaternary. However, no evidence of young movement has been uncovered for the Bentong segment in the peninsula. Two anorogenic volcanic events produced basaltic lavas in two areas, early Palaeogene at Segamat, Johor, 66 Ma ago and 1.8 Ma ago in the Kuantan area (Metcalfe, 1988, 1996a, 1998; Tjia, 2010).

Granite which is the major igneous rock that is abundantly available in Peninsular Malaysia occupies almost half the peninsula (Figure 2.4). It is distributed into three parallel belts, i.e. Western, Central and Eastern belts, running roughly north south along the length of the Peninsula and commonly forming topographic highs, notably in the Main Range. The Western Belt consists of the Main Range, the Bintang and Kledang Ranges and other granite further west.

The ages of the granites range from Permian to Cretaceous, with the majority of Triassic age during which all the older strata were folded and deformed (Bignell & Snelling, 1977). Granitic rocks underlie an area of about 738 sq km i.e. about half the area of Kinta District (Ingham & Bradford, 1960; Gobbett, 1971).

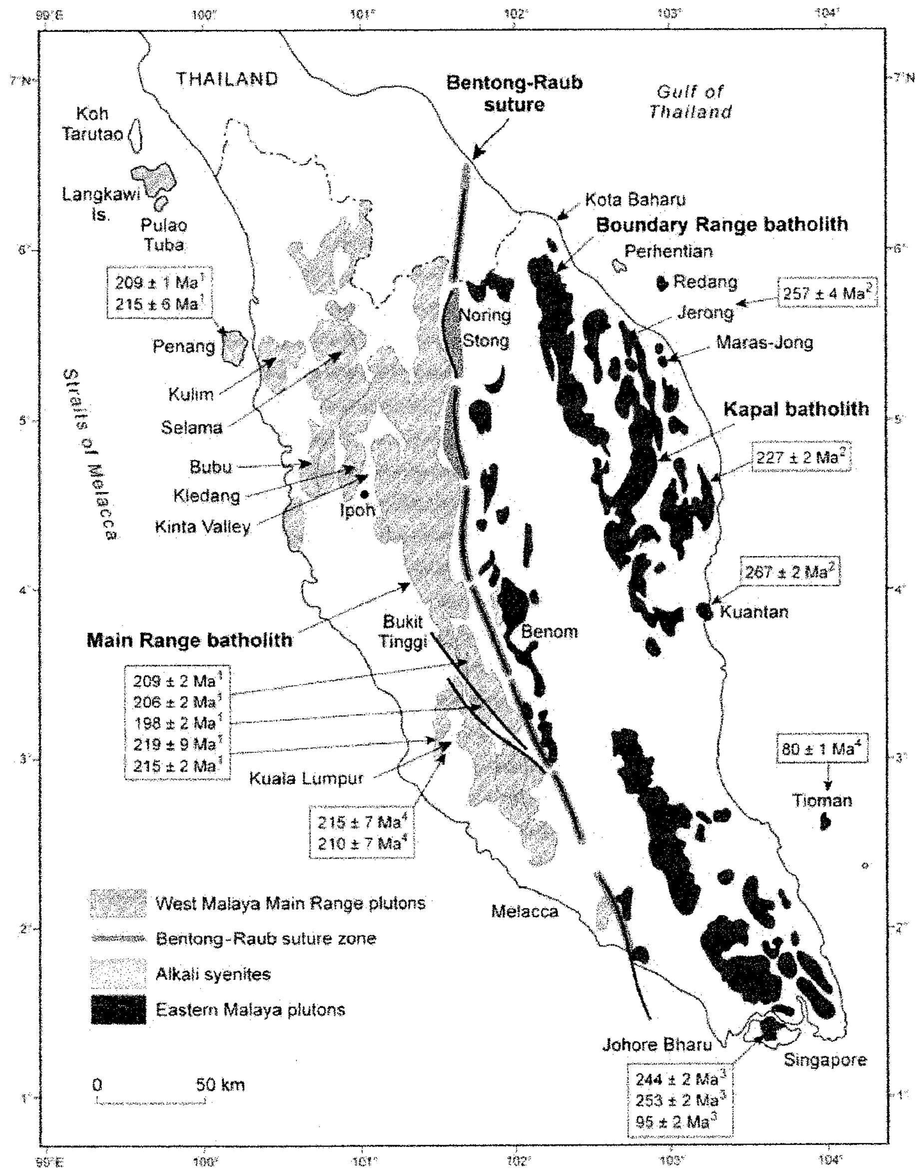

Figure 2.4: Granitoids of Peninsular Malaysia, modified after Cobbing et al. (1986), Ghani (2009) and Hutchison and Tan (2009), showing distribution of main plutons and granitic bodies in relation to the Bentong-Raub suture zone. The approximate boundaries of the West Malaya granite province, the Bentong-Raub suture zone, and the East Malaya province are shown together with locations of all granites dated by U-Pb zircons, from Searle et al. (2012).

The term "The Yunnan-Malaya Geosyncline " was introduced by Burton (1967) to describe the belt of Lower Paleozoic rocks that extends from the Malay Peninsula northwards through Thailand, Burma and China. Jones (1968) interpreted the stratigraphy and north-south facies belts of the Malayan portion. The geosyncline and its various zones (miogeosyncline and eugeosyncline) are present in Peninsular Malaysia. The formation of geosynclinal ridge (Main Range) divided the trough into two zones with miogeosynclines to the west and eugeosynclines to the east (Foo, 1983). The "miogeosynclinal" interpreted by Jones (1968) as representing shelf sediment or platform facies in the west, and "eugeosynclinal" facies which containing radiolarian cherts, basic igneous rocks and thick sections of deep-marine clastics in central Peninsular Malaysia (formerly Malaya).

The geosynclinal concept was replaced by plate tectonics; Hutchison (1973) placed the data in a plate tectonics context (the modern equivalents of the geosynclinal concepts) and interpreted the "eugeosyncline" as a former trench in a subduction system (Raub-Bentong suture). He also suggested that eugeosynclinal sediments as oceanic. Meanwhile, miogeosynclinal or shelf sedimentation was part of Gondwanaland. The geoanticline represents an accretionary prism with volcanic input from the forearc and the mud rich deep water sediments (Metcalfe, 2000; Lee, 2009).

2.2.3 Paleozoic Formation in the Western Zone

Peninsular Malaysia has traditionally been divided into three zones. Each of these three zones is characterized by its own stratigraphy, metamorphism, structure and geological history. These zones have been variously called the Western, Central and Eastern "Belts" Zones" or "Domains" (Figure 2.5). Some authors recognize a Northwestern "Zone" or "Domain (Hutchison, 1975, 1977; Foo, 1983; Khoo & Tan, 1983; Tjia, 1999; Metcalfe, 2000; Lee. 2009).

The Western Zone is subdivided into the northwestern zone and western zone (represent the miogeosynclinal deposition of Jones, 1968) (Foo, 1983).

Peninsular Malaysia is divided into three basins (Western, Central and Eastern) on the basis of their distinctive tectonic and sedimentary histories (Aw, 1978). The Western Basins includes most if not all, Lower Paleozoic formations as well as some upper Paleozoic formations (Foo, 1983). The western zone covers a large area stretching from the Perak-Thai border southward to the state of Malacca, while the northwestern zone covers Langkawi, Kedah and Perlis area.

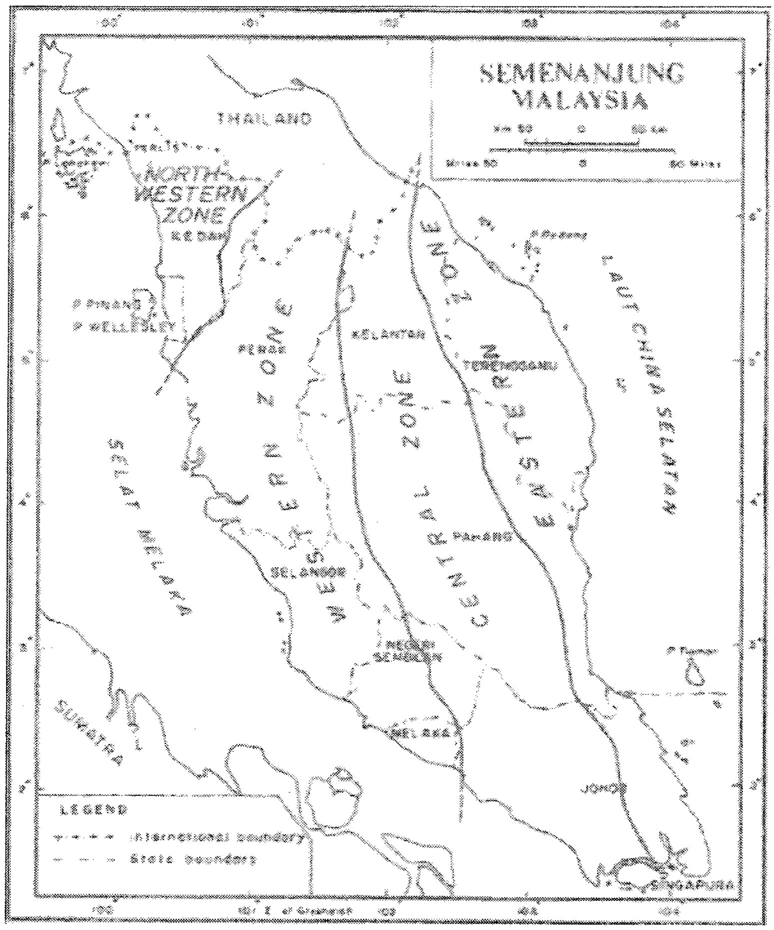

Figure 2.5: Map of peninsular Malaysia showing all three zones and the northwestern zone, from Foo (1983).

The Lower Paleozoic rocks are confined to the northwestern zone of the Western Zone while the upper Paleozoic rocks found in all three Zones. The geological ages of the rock formations become younger from west to east. The oldest stratigraphic units ranging in age from upper Cambrian to Permian are exposed in Langkawi, Kedah and Perlis in the northwestern zone of Western zone (Foo, 1983; Lee, 2009).

Two main stratigraphic groups are the Baling group in the north Perak and the Lower Paleozoic Bentong group (consisting of the Pilah Schist and its correlatives) which occurs as unbroken belt along the eastern foothill of the Main Range. The upper Paleozoic rocks which crop out along the western zone are the Silurian to Permian Kinta Limestone, Terolak Formation and Kati Formation in Perak. Along with them are the lower Palaeozoic Dinding and Hawthornden Schists and Kuala Lumpur Limestone and Carboniferous to Permian Kenny Hill Formation in Selangor (Figure 2.6).

The limestone and argillites of the Kinta Valley are classified under the Kinta Limestone and the Baling Group respectively while the westerly clastics along Perak River are grouped under the Kati Formation (Foo, 1983). The western zone formations are mostly poorly dated by fossils because thermal metamorphism has affected most of the sequences (Alexander, 1959; Foo, 1983; Lee, 2009).

Sediments of the Upper Paleozoic (Carboniferous to Permian), e.g., the Kenny Hill Formation, Singa Formation, and Kati Formation are unconformable over the Lower Paleozoic sequences. There are a number of similarities (both lithologically and stratigraphically) between the clastic sediments of the Singa, Pasu Kulong Formations (in the northwestern zone), Kenny Hill Formation in Selangor and Kati Formation in west-southwest of Kinta Valley (Foo, 1983, 1990; Wong, 1991; Hutchison, 2007).

Broadly, the Paleozoic clastics Formations of the western zone of Peninsular Malaysia are made up mainly of Kubang Pasu Formation exposed in Langkawi, Kedah and Perlis, Kati Formation in Perak and Kenny Hill Formation in Selangor (Figure 2.7) (Foo, 1983; Hutchison, 1994, 2009b; Lee, 2009; Jasin & Harun, 2011).

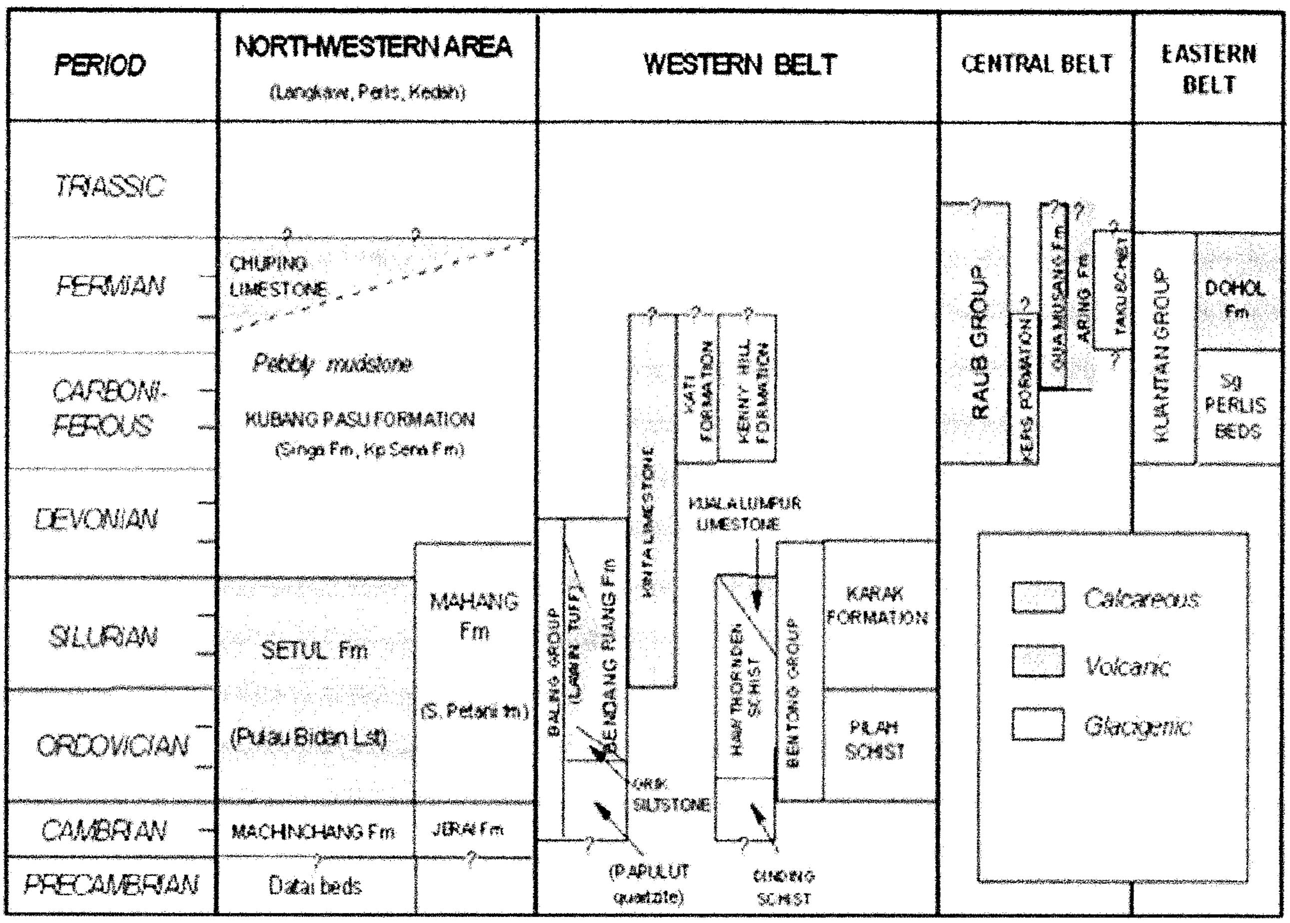

Figure 2.6: Schematic classification and correlation of Paleozoic formations of Peninsular Malaysia modified after Foo, (1983) with additions.

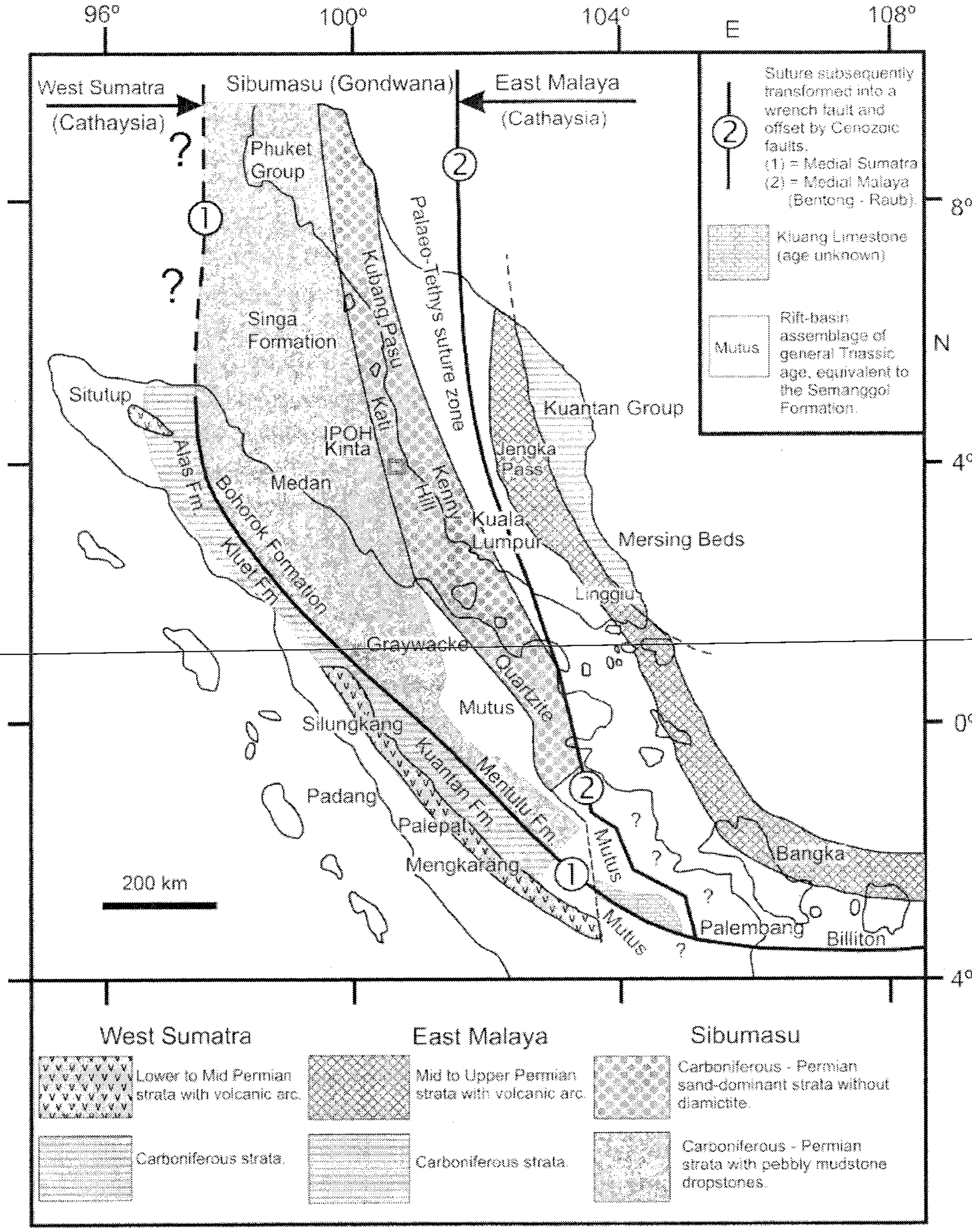

Figure 2.7: Proposed subdivisions of Peninsular Malaysia and Sumatra into Gondwana and Cathaysia Carboniferous-Permian entities, the red square represents the Kati Formation (study area in Western Malaysia),from Hutchison (2009a).

2.3 Geology of the Study Area and Previous Work

For almost a century, many studies have been conducted to investigate the geology of the Kinta Valley, especially during the first half of the 20th Century when Kinta Valley was experiencing a steady growth in tin mining and considered the richest and largest producer of tin ore in the world (Ingham & Bradford, 1960; Rajah, 1979; Wong, 1991; Lee, 2009).

Early geologists began to investigate the rocks that were exposed in the Kinta Valley in the (1913-1960) period and they mainly focused on classifying major classes of the rocks and described their distribution, in particular the geological Formations which are renowned for hosting a wide variety of mineral resources e.g., the Paleozoic limestones and the Quaternary alluvial deposits. Despite all that, a few notable attempts have been made to study the Paleozoic clastic deposits that are exposed in the west-southwest part of the Kinta Valley and precious little is known about their mineralogical, textural and sedimentological characteristics.

Scrivenor (1913) noted that an isolated range of quartzite, conglomerate and shale were found in the northern part of Perak between Krian (near Kedah) and Larut (Taiping) known as the Semanggol Range. The quartzite hills are found near Teluk-Intan (Bukit Ttunggal). Moreover; in Selangor such hills form a large part of the State "Kenny Hill Formation" (Scrivenor, 1913). The best descriptions of the arenaceous rocks exposed in Bukit Tunggal are interestingly found in Ingham (1938) and Wong (1991).

One of the best early descriptions of rocks of the Kinta Valley are those of Scrivenor and Jones (1919), in particular the Dindings area (currently known as Manjung) where they identified three dominant geological units namely, the Carboniferous-Permian calcareous series, the Triassic arenaceous series and the Mesozoic granites (Ingham & Bradford, 1960; Wong,1991).

2.3.1 Geology of Kinta Valley and the adjacent areas (The Kinta District)

The Kinta Valley is a narrow elongated alluvial plain, situated up to 43m above sea level in the state of Perak, near the western coast of Peninsular Malaysia. The latitudinal location of Kinta Valley is between 4°45' and 4°15'N and the longitudinal extent, 101°15' and 101°00'E (Figure 2.8). The Valley is bordered by two granitic masses. It lies to the west of the Main Range and east of the Kledang Range and extends southward. Kinta Valley is drained by Sungai Kinta from the Main Range in the northeast down to Bota in the south-west. Major tributaries of Sungai Perak are draining the valley and running through the limestone karstic towers from the east and northeast of the valley (Ingham & Bradford, 1960; Muhammad &Yeap, 2002; Nasution & Lubis, 2005).

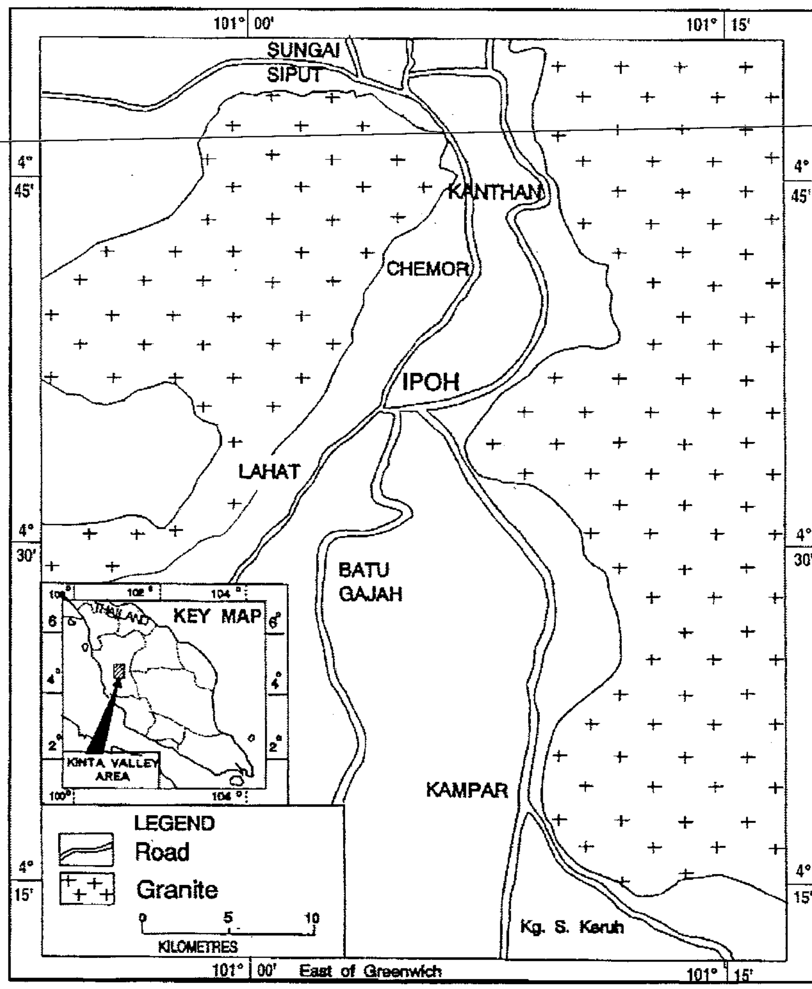

Figure 2.8: Location map of the Kinta Valley, from Fontaine and Amnan, (1995).

The Kinta Valley measures 58km from north to south and 45km from east to west and trends approximately south-southwest. The Kinta District covers major towns such as Chemor, Tanjung Rambutan, Tambun, Ipoh, Menglembu, Lahat, Papan, Malim Nawar, Simpang Pulai, Pusing,Batu Gajah, Tronoh, Tanjung Tualang, Gopeng, and Kampar. The Kinta Valley encompasses mainly carbonates rocks which are widespread and vary in thickness with rare clastic sequences (Fontaine & Amnan, 1995; Muhammad &Yeap, 2002).

The Kinta Valley is underlined by a sequence of sedimentary rocks ranging in age from Silurian to Permian. The bedrock is mainly made up of crystalline limestone or dolomite with minor arenaceous and argillaceous rock (subordinate shale and rare sandstone) (Ingham, 1938; Ingham & Bradford, 1960; Rajah, 1979; Wong, 1991; Fontaine & Amnan, 1995). These bedrocks are known either by exposures or boring especially in the vicinity of mining areas (Hutchison, 2007).

The Paleozoic rocks are well exposed in the Kinta Valley and the surrounding district of Kuala Kangsar. Most of the sedimentary rocks in the Kinta Valley are Devonian in age. Rocks of Silurian age are present in the northern part, whereas rocks of Carboniferous underline areas in the southwestern part of the valley. However, Triassic sediments are absent in the Kinta Valley (Wong, 1991; Lee, 2009).

During the late Paleozoic, Kinta Valley was a stable shelf with ongoing calcareous sedimentation interrupted by argillaceous invasions from the deeper more rapidly subsiding flank from time to time, (Wong, 1991).

The strike of these Paleozoic rocks is generally N to NNW and dip steeply to the west or southwest, with beds folded or overturned (Lee, 2009; Rajah, 1979).

The Paleozoic rocks of Kinta Valley have been affected by low grade regional and thermal metamorphism caused by the intrusion of granite and associated late phase minor intrusives into the sedimentary sequences that occurred probable Triassic age (Rajah, 1979; Cobbing et al., 1992). The vast expanse of the Kinta Valley plain is covered with the alluvial deposits (the Quaternary deposit). It is also widespread along the river valleys in the granite hills.

The thickness of the alluvial deposits varies considerably across the areas and gradually increases southward from 6m near Ipoh to more than 30m in the southern part (Ingham & Bradford, 1960; Suntharalingam, 1968; Rajah, 1979; Hutchison, 2007).

Generally, the granite of the Kledang Range splits up this area into two different Paleozoic formations (sections), with the Kinta Limestone Formations in the east and Kuala Kangsar Formations to the west (Gobbett & Hutchinson, 1973; Gobbett, 1971).

- **Kinta Limestone Formations**

The Paleozoic limestones of the Kinta Valley (Silurian to Permian age) are well exposed at the eastern flank of Kledang Range and narrowly confined to the central axis of the valley. These deposits include several relatively thin intervals of argillaceous beds and exceed 3000m in stratigraphic thickness. The Kinta Limestone Formation was folded and recrystallised by regional metamorphism in the Late Triassic (Ingham & Bradford, 1960; Suntharalingam, 1968; Gobbett, 1971; Foo, 1983).

- **Kuala Kangsar Formations**

Farther north along the western flank of the Granite Mountains of the Kledang Range, the Paleozoic Kuala Kangsar clastics are exposed. These rocks have been divided into three formations by Foo (1990) namely, the Pondok Marbles, the Kati Beds and the Salak Baharu Beds.

2.3.2 Sungai Siput district and adjacent areas (northern part of the Kinta Valley)

Geological investigations and mapping in Sungai Siput and the adjacent areas were carried out by Savage (1937). The majority of the area studied lies within the administrative district of Kuala Kangsar and extends to the Kinta District.

Five distinctive stratigraphic units (formations) were recognized:

1) Limestone and associated rocks
2) Quartzite and associated rocks
3) Quartz-porphyry (foliated and not foliated)
4) Granite and Allied rocks
5) Alluvium

- **Quartzite and associated rocks**

Savage (1937) has reported the presence of a formation composed mainly of clastic rocks (sandstones and shales), the rocks which he called "Quartzite and associated rocks". These clastic rocks crop out in the north-northeast and are best developed in the east-central portion of the Sungai Siput area. The quartzite and associated rocks consist mainly of quartzite, schist, sandstone and shale. No quartzite-conglomerate has been found at these beds and they are also unknown in the Kinta Valley. No fossils have been found in this formation and "even if it were found" it seems probable that the metamorphic processes had obliterated them.

Savage (1937) believed that the sandstone and the shale are weathering products of the quartzite and schist. Furthermore, he has mapped this formation as Triassic age.

This formation has been intensely folded and various values of dip-angles have been recorded. Moreover, no general direction of the trend can be determined from the strike-readings. Many outcrops in the Sungai Siput District were mapped by Savage (1937) and they belong to the Quartzite formation except those found interbedded with limestone or associated with exposures of limestone. Nevertheless, it is now generally regarded as belonging to (the Permo-Carboniferous age) limestone with interbedded schist.

2.3.3 The Paleozoic west and southwest of the Kinta Valley

According to Ingham and Bradford (1960), the rocks of the Kinta Valley can be divided into three main facies:

1) The calcareous series
2) The granites and allied rocks
3) The arenaceous series

- **The calcareous series**

The sedimentary rocks underlying the Kinta Valley are mainly calcareous and they are believed to be of Carboniferous age. The Permian limestone is known to be present north of Tanjung Rambutan and west of Kampar.

Suntharalingam (1968) has reported that the limestone west of Kampar have yielded molluscan brachipod and coral faunas of Silurian, Devonian, Carboniferous and Permian (Suntharalingam, 1968; Bin Leman, 1990; Lee, 1992).

The calcareous series are composed mostly of relatively pure limestone, dolomite and ferroandolomite and occupy about 673km2 of the valley. Some limestone beds have been metamorphosed and recrystallized into marble. Locally, the calcareous rocks are interbedded with argillaceous beds. Furthermore, there are a series of spectacular limestone hills with steep walls arising from the alluvial plain of the Kinta Valley, in particular the eastern part of the valley. The limestone surfaces usually exhibits irregular pinnacles and commonly form extreme karst topography in mines working on stanniferous alluvium, (Ingham & Bradford, 1960; Suntharalingam, 1968). These limestone hills form striking topographic features which are easily recognizable on aerial photographs and satellite images. Foo, (1983) believed that the Kinta Limestone (the calcareous series) may be correlated with the quartzite and schist unit of Savage (1937).

- **The arenaceous series**

The arenaceous rocks are extensively exposed west and southwest of the Kinta Valley (Figure 2.9). These rocks crop out in the southwest part of Tronoh and extend for some distance to expose along the Siputeh-Parit road and Tanjung Tualang. The arenaceous rocks are composed mainly of quartizes with subordinate shist bands, derived from shales and sandstones. The arenaceous outcrops are highly weathered. Commonly sandy loams over sandstone, limonitic concretion and ferruginous gravel can be encountered where shale predominates. Most of Kinta Valley arenaceous rocks are found interbedded with limestone. Therefore, they are included in the calcareous series, except those at localities in the southwest part of Tronoh to southwest Tanjung Tualang. Generally these rocks are more arenaceous than those included in the calcareous series and they therefore have been left unaltered as Triassic.

Ingham and Bradford were of the opinion that, even though these arenaceous rocks appear to be disconnected (on the geological map); they are believed to constitute part of the same mass. No fossils have been found, with the exception of poorly preserved plant remains found in shale by Savage (near the old 15 ½ mile post) along the Siputeh and Parit road. Due to the paucity of good exposures and lack of fossil evidence, no exact boundary can be drawn between the arenaceous and calcareous series.

Ingham and Bradford believed that these arenaceous series to be Triassic age (as part of the Quartzite Range) and they suggested that these arenaceous rocks are lithologically similar to Semanggol Formation (near Taiping). Ingham and Bradford (1960) probably correlated this arenaceous series with the Semanggol Formation for the reason that Semanggol Formation was the only arenaceous Formation that has been dated by fossils (at that time when they conducted their study) which adjacent to their map area (Kinta Valley).

- **The argillaceous series**

The argillaceous rocks consist essentially of shale, phyllite and schist with subordinate siltstone and (quartzite) sandstone. These argillaceous rocks are well exposed in many places along the Kinta Valley and the largest outcrops extend from Batu Gajah to Tanjung Tualang. Ingham and Bradford (1960) included the argillaceous and arenaceous series in the calcareous series. These clastic sequences (arenaceous-argillaceous) have traditionally been mapped as part of the Triassic system.

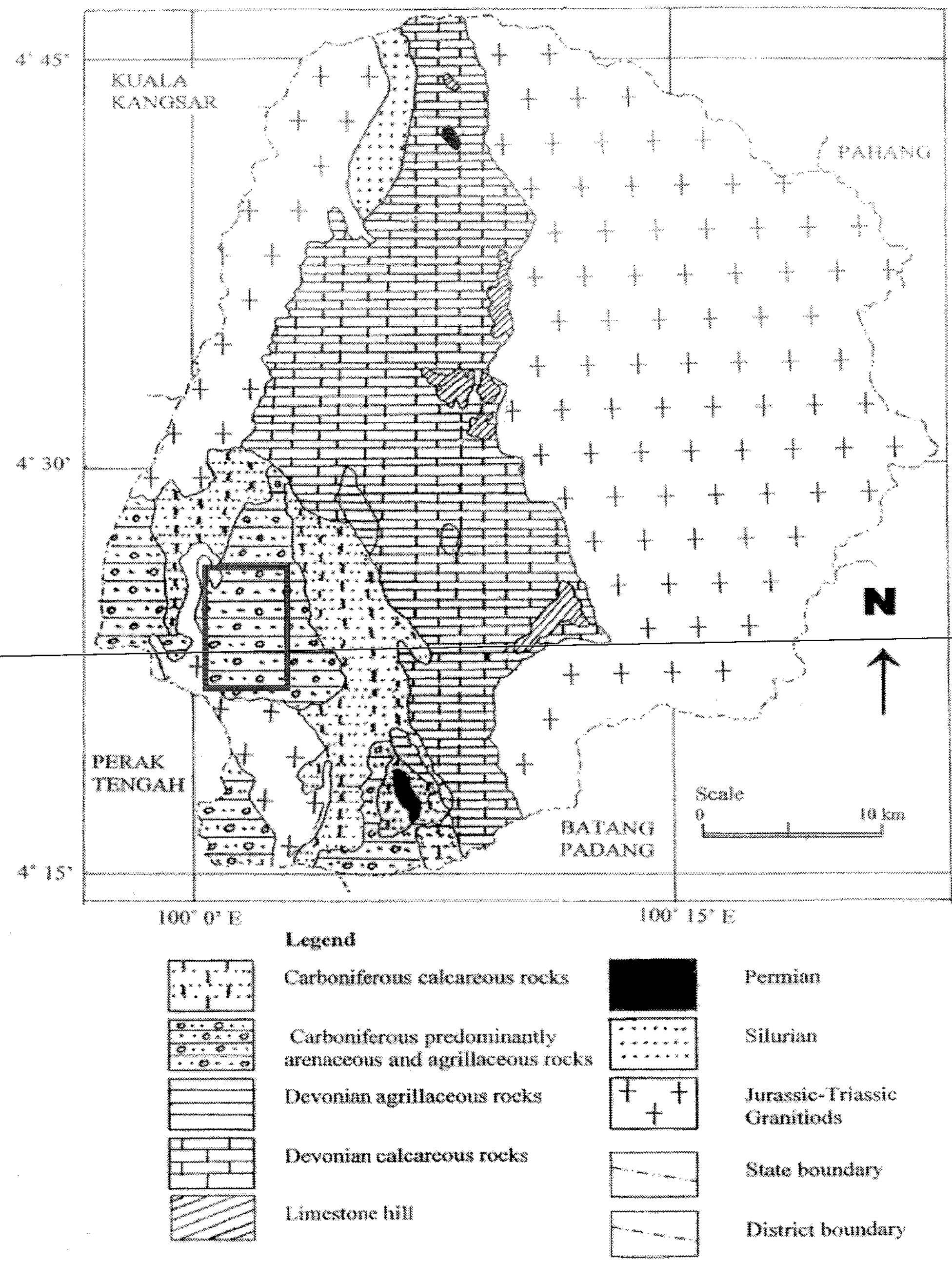

Figure 2.9: The geology map of the Kinta District based on Ingham and Bradford (1960) work and on the Geological Map of West Malaysia, 7Th Edition (1973), from Muhammad &Yeap (2002).

2.3.4 Taiping - Kuala Kangsar and the adjoining areas (north-west Kinta Valley- north-central of Perak)

Foo (1990) reported the Paleozoic and Mesozoic exposures of Kuala Kangsar and Taiping areas. The Mesozoic era is well represented by the Triassic age Semanggol Formation in Taiping. In Kuala Kangsar, the Paleozoic formations have been divided into three beds:

1) The Pondok Marbles
2) The Kati Beds
3) The Salak Baharu Beds

Fossils have not been discovered in all of the three beds. Therefore, the age and origin of these beds are inferred indirectly from field relationships, mainly based on the proximity of occurrence and contiguity as well as the similarities in lithological character and structural style.

Foo (1983, 1990) suggests that the age of the Salak Baharu Beds to be Devonian to Permian, while the clastic Kati Beds and Pondok Marble are interpreted to be younger than the Salak Baharu Beds and were deposited during the Carboniferous to Permian age (Figure 2.10). The distribution of these facies show a lateral change from a more calcareous facies Salak Baharu and Sungai Siput area to more arenaceous facies in Kuala Kangsar.

- **Pondok Marbles**

The term "Pondok Marbles "refers to a calcareous formation that crop out in Gunung Pondok. This formation gets its name from Gunung Pondok, which is located about 15km to the north of Kuala Kangsar town. These rocks form a steeply eroded hill and exhibit typical karst topography. Moreover, the occurrences of a tongue of Triassic granite in the limestone from an old quarry face were observed by Foo (1990). Pondok Marbles consist of recrystallized limestone and are massive and coarse-grained (limestone, massive, calcite, marble). Locally, there are laminations of black carbonaceous and green veins of diopside. These veins show an association of skarn minerals. No fossils could be found in the Pondok Marbles because of the recrystallized nature of this limestone. The contact of the Pondok Marbles with Kati Beds or other neighboring sediments has not been observed. Foo (1990) suggested this marble a late Paleozoic age.

Name of the Unit	Age
1. Superficial deposit	Quaternary
2. Enggor coal beds	Tertiary
- - - - - - - - - - Unconformity - - -	- - - - - - - - - - - - - - - - - - - -
3. Granite and allied rocks	Mesozoic (Triassic)
4. Semanggol formation	
5. BatuKurau limestones	
- - - - - - - - - ? - - - - -	- - - - - - - - - - - - - - - - - - - -
6. Pondok Marbles Beds	(probably Carboniferous to Permian)
7. Kati Beds	
8. Salak Baharu Beds	late Paleozoic

Figure 2.10: Geological succession of Kuala Kangsar formation modified after Foo (1983, 1990).

- **The Kati Beds (Formation)**

The term “Kati Beds” was introduced by Foo (1990) to describe a formation which occurs particularly in the Kuala Kangsar area and extends southward along the western bank of Sungi Perak into the Kinta Valley (west and southwest) (Figure 2.11). This Formation lies between the granites of the Bintang and Kledang Ranges and predominantly consists of interbedded argillaceous and arenaceous rocks (Foo, 1983, 1990; Wong, 1991; Hutchison, 2007; Lee, 2009).

In general, these rocks are poorly exposed, very scarce and sparsely distributed. Kati Beds outcrops are deeply weathered due to their low topographic positions and the tropical conditions, except for the more resistant metasediments. The existence and position of the Kati Beds have been confirmed mainly by boreholes as it is largely located within the dense tropical rain forest or is covered by Quaternary alluvium (Foo, 1990; Wong, 1991; Loh, 1992).

The actual thicknesses of these rocks exposed in Kuala Kangsar area are very difficult to determine, because some of these beds are highly folded (Foo, 1990). However, at

Cangkat Hulu Denak (Lumut and Teluk-Intan area) the exposed thickness of the Kati Beds estimated to be 900m (Wong, 1991).

Kati Formation is generally composed of a predominantly monotonous sequence of interbedded metamorphosed reddish brown carbonaceous shale, mudstones and fine grained sandstones, with minor siltstone (Foo, 1990; Wong, 1991).

The siltstone and shale beds are characteristically laminated or thinly banded and vary from gray to dark gray. The thicknesses of sandstone and siltstone are in general, 7-10cm, but can reach meters thick. Shale beds are much thicker, about 30cm, gray to whitish-gray, although in places, secondary staining may render a pinkish coloration to the shale. Quartzite-conglomerate which is common in some other parts of Peninsular Malaysia appear to be entirely absent in the Kati Beds (Foo, 1983, 1990; Wong, 1991; Hutchison, 2007; Lee, 2009).

Even though Kati Beds can be traced along its strike northwards between the granites of the Bintang and Kledang Ranges, no contact with younger sediments or calcareous rocks were observed apart from the Quaternary alluvium (Ingham & Bradford, 1960; Foo, 1990; Wong, 1991). Moreover, since no signs of unconformity between the Kati Beds and Salak Baharu Beds have been found, Kati Beds are interpreted as a lateral facies change of the Salak Baharu Beds (Foo, 1990).

No fossils have been found within the Kati Beds and a probable upper Paleozoic Carboniferous to Permian age is assigned (Foo, 1990). Moreover, Foo (1990) disagreed with Ingham (1938) and Ingham and Bradford (1960), believing that these arenaceous series (Kati Beds) is older than the Semanggol Formation in northern Perak which is Triassic. Kati Beds were interpreted to be older than the Semanggol Formation, based on dissimilarities in the lithology and the style of folding (as Kati Beds are more highly flexured (folded) than the Triassic Semanggol Formation) (Foo, 1990; Wong, 1991; Hutchison, 2007).

Kati Beds is weakly metamorphosed because it was not directly affected by the regional metamorphism as the superimposed thermal metamorphism is largely confined to the far northeastern part of the area (the vicinity of a large granitic intrusive) (Wong, 1991; Foo, 1990).

These arenaceous rocks are locally highly folded into relatively open anticlines and synclines and in the vicinity of the granite intrusive these rocks are metamorphosed to hornfelses. A fault contact between the Kati Beds and the granite was observed along Sungai Dal, in Kampong Buaya (Foo, 1990).

From observation on outcrops reported by Wong (1991), besides the regular bedding planes the most noticeable primary sedimentary structures occurring within the Kati Beds are rhythmic bedding, current structures like load structures, flame structures and flute casts with some graded sandstone beds (Foo, 1983, 1990; Wong, 1991).

Foo (1990) stated his belief that Ingham and Bradford (1960) wrote of the same Formation in the Kinta Valley (the west and southwest portion of the valley). He based his opinion on the correlation between lithology and structures of the arenaceous rocks of Kuala Kangsar area and the arenaceous series of the west and southwest of the Kinta Valley area.

Furthermore, Foo (1983) renamed Kati Beds to Kati Formation after taking into account Wong's work in the Lumut and Teluk-Intan area.

The Kati Beds is interpreted as equivalent to the Kubang Pasu Formation (Foo, 1983; Hutchison, 2007). The Upper Paleozoic Kenny Hill formation of Kuala Lumpur area can be correlated with Kati Beds (Wong, 1991).

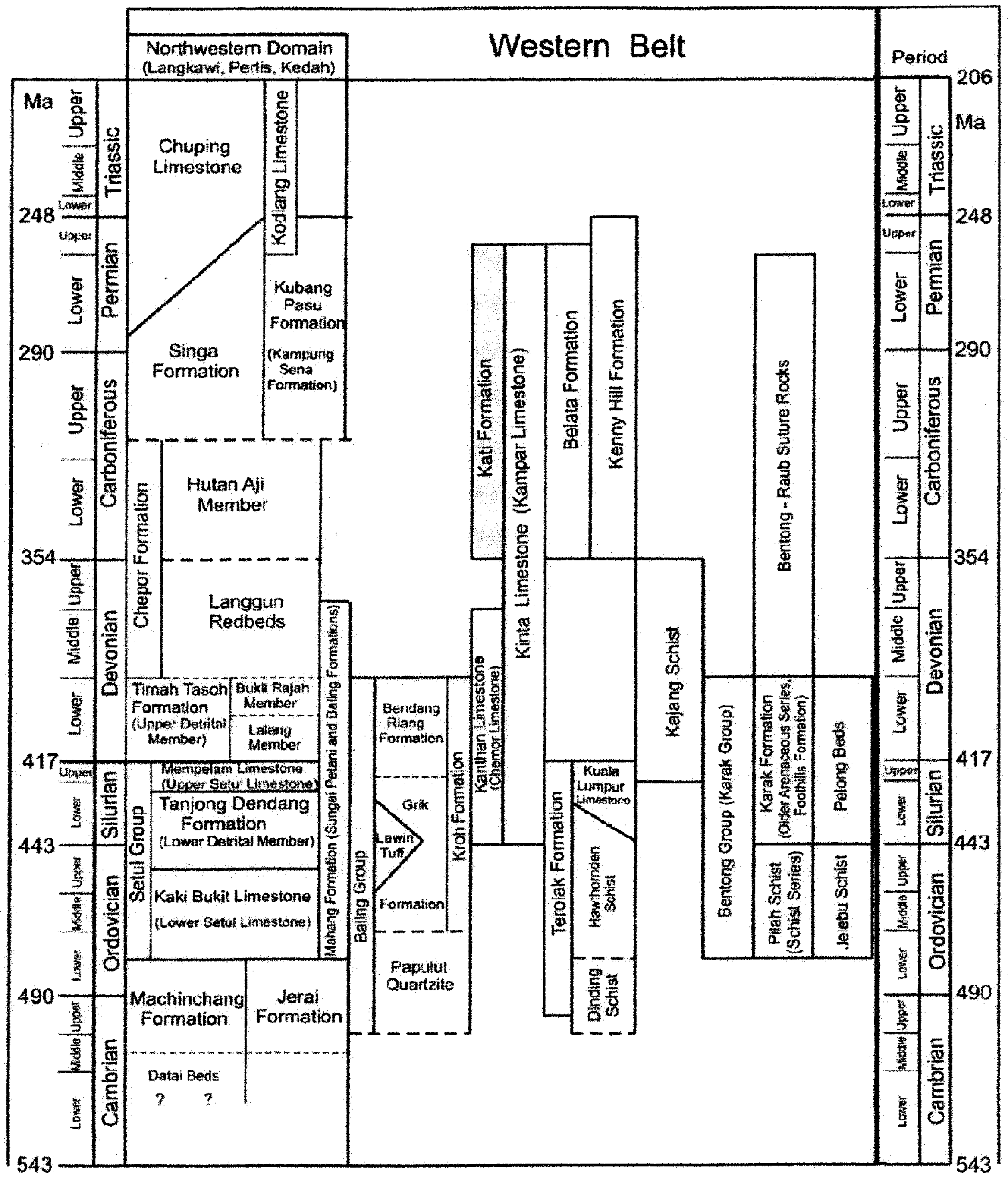

Figure 2.11: Stratigraphic chart of Paleozoic sequences of the western belt of Peninsular Malaysia modified after Lee (2009).

- **Salak Baharu Beds**

Salak Baharu Beds are exposed in the Enggor Valley in the Salak Baharu area and this is where the name of the beds comes from. The outcrops are not widespread in the Salak Baharu area and its thickness is not known. Foo (1990) reported a band of near-vertical bedded rocks in mine holes in the Salak Baharu area; these beds consist mostly of gray to black carbonaceous shale and spotted hornfelses with interbedded sandstone calcarenite, chert and micaceous siltstone.

Along the contacts with the Triassic granite, some beds of the Salak Baharu are characterized by a distinctive set of contact metamorphism features (Lee, 2009).

Fossils are not found in these rocks. Moreover, according to Foo (1990) Salak Baharu Beds are believed to be a continuation of the limestone-shale formation referred by Savage (1937) as a Devonian limestone unit in the area around Kanthan Estate, Southeast of the Sungai Siput River.

Formerly all these units are called calcareous facies and dated by Savage (1937) as Carboniferous-Permian age. The age of the Salak Baharu Beds is believed to be late Paleozoic Devonian to Permian (Foo, 1990).

- **Semanggol Formation**

Semanggol Formation was named after Gunong Semanggol by Alexander (1959), and it refers to a fault-bounded argillaceous-arenaceous rock that lies to the east of the carbonate platform and exposed in the Semanggol Range in north Perak. These clastic deposits occurred restrictedly in the northwestern domain of Peninsula Malaysia in the western zone in three major areas. It stretches over an area from the northern border and central of Kedah and extended southward to Perak. The formation was probably deposited in the same basin which was later separated into three areas by wrench faults (Burton, 1973; Abdullah et al., 1989) (Figure 2.12).

Semanggol Formation is exposed about 13km northwest of Taiping in northern Perak and covers approximately 90km2 of the area (Foo, 1990). The Semanggol Formation was formerly known as the Younger Arenaceous Series (Alexander, 1959; Foo, 1990).

Generally, Semanggol Formation consists of chert, shale, sandstone and conglomerate. Two dominant facies groups are observed in Semanggol Formation, namely, a rudaceous-arenaceous facies of intraformational conglomerate and sandstone and argillo-arenaceous facies of the rhythmically bedded sandstone and shale (Foo, 1990).

Generally, Semanggol Formation has been divided into three members (Hutchison, 2007):

1) Conglomerate member of lutite and interbedded arenite and important conglomerate horizons.
2) Rhythmite member flysch-like sequence of interbedded thin arenite and lutite showing turbidites characteristic.
3) Member of thin bedded lutite and arenite containing important chert beds.

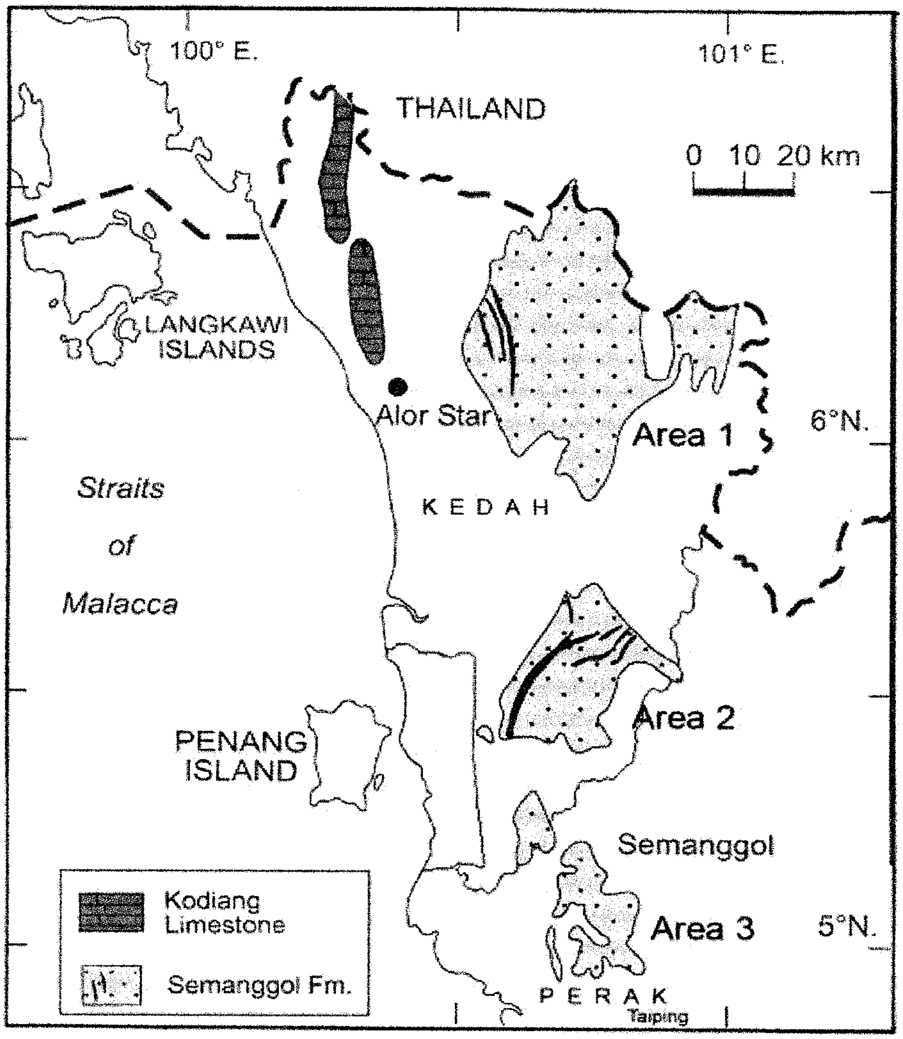

Figure 2.12: Map showing the distribution of the Semanggol Formation in northwest Peninsular Malaysia, separated into three areas by wrench faults, modified after Lee (2009) and Hutchinson (2007).

The contact between rocks of the Semanggol Formation and alluvium is very indistinct in the field. Furthermore, the thickness of the Formation could not be determined due to the tightly folded nature of the rock and the absence of marker beds. However, the sequences are believed to be no less than 760m thick (Foo, 1990).

Semanggol Formation is dated as Triassic in age. From the upper part (formation containing chert) which is Triassic Ladinian to Norian in age, fossils like Posidonia, Halobia and Daonella were found (Foo, 1990; Fontaine, 2002; Lee, 2009). The Semanggol Formation represents a flysch type deposit that was formed due to the impact of sediment gravity flows. The sedimentary environment for this formation has been interpreted as deep-marine sediments based on sedimentological and palaeontological studies (Metcalfe et al., 1982).

2.3.5 Tapah and Telok Anson (Teluk-Intan) and adjoining areas

Ingham (1938) examined the rocks exposed in the Taph and Telok Anson area (currently known as the Teluck-Intan), the deposits to which he referred to as "Quartzite and associated rocks". Ingham correlated this Quartzite Formation with "the arenaceous series "as Triassic age (Triassic system). Furthermore, since fossils are absent from these deposits, his conclusions seem to be mainly based upon the lithological similarity.

The quartzite formation consists of four major lithologic types: quartzite, schist, phyllite and shale, along with their weathered products sand, sandstone and clay. Quartzite-conglomerate which is common in the some other parts of Peninsular Malaysia appears to be completely absent.

The beds strike approximately north to south with dip about 45° towards east. The quartzite beds attain a thickness of several feet, interbedded with thin layers of shale (gray, green and red). Iron staining (red or yellow) commonly occurs on the outcrop surfaces. When fresh, the quartzite is hard, pale gray. Some of the quartzite beds contain small quartz veins (less than1/4 inch).

Two types of quartzite encountered in the boreholes belong to the quartzite formation they are:

1) Massive, white, loamy sand.
2) Weathered impure quartzite.

Quartz grains are about pin-head size, well sorted. However, in some samples from bores there are larger grains scattered in the finer matrix. Some quartz grains exhibit strain polarization (Undulose extinction). Among the most abundant accessory minerals observed were Tourmaline and Mica. Leucoxene, ilmenite and rutile exist in small amounts. Pyrite and siderite are found in samples collected from boreholes and they show alteration to iron oxide on exposed surfaces. No chert, phyllite or schist has been observed in outcrops. Nevertheless, black phyllite, chert and gray clay were found in fragments from borehole.

This Quartzite Formation is considered as the base bedrock of Taph and Teluck-Intan area beneath the alluvium.

2.3.6 Lumut and Teluk-Intan and adjoining areas (southwest of Kinta Valley)

Three sedimentary successions have been recognized by Wong (1991) in the Lumut, Teluk-Intan and adjoining areas, informally referred to as:

1) Kati Beds
2) Tualang Limestone
3) Gelubi Schists.

These latter two formations make up the so-called formally "the calcareous series". These sediments are affected by low grade regional and thermal metamorphism and are folded with axes striking north to northwest. Kati Beds underlie most of the quaternary deposit in the map area (Wong 1990; Loh, 1992).

No fossils have been found within these units. However, they are believed to be contemporaneous and have been assigned a Carboniferous-Permian age based purely on lithological similarity to rocks of known age in the neighbouring areas.

Wong (1991) agreed with Foo (1990) that, Ingham (1938) wrote of the same Formation (arenaceous series) in Tapah and Telok Anson (the south part of Kinta Valley). Moreover, he reported that some Carboniferous and Permian fossils have been discovered by Too (1974) in the limestone formation thought to be the later extension of Tualang Limestone (1km to the east of Lumut and Teluk-Intan area) (Wong ,1991). Wong (1991) suggested that the lithologic difference between these units is due to facies changes. Moreover, these Paleozoic units are interpreted to form in part a depositional contact. Wong (1991) concluded that the map area was essentially a stable sedimentary basin in the late Paleozoic as indicated by a thick sequence of conformable carbonate and clastic sediments of carboniferous to Permian age (Figure 2.13).

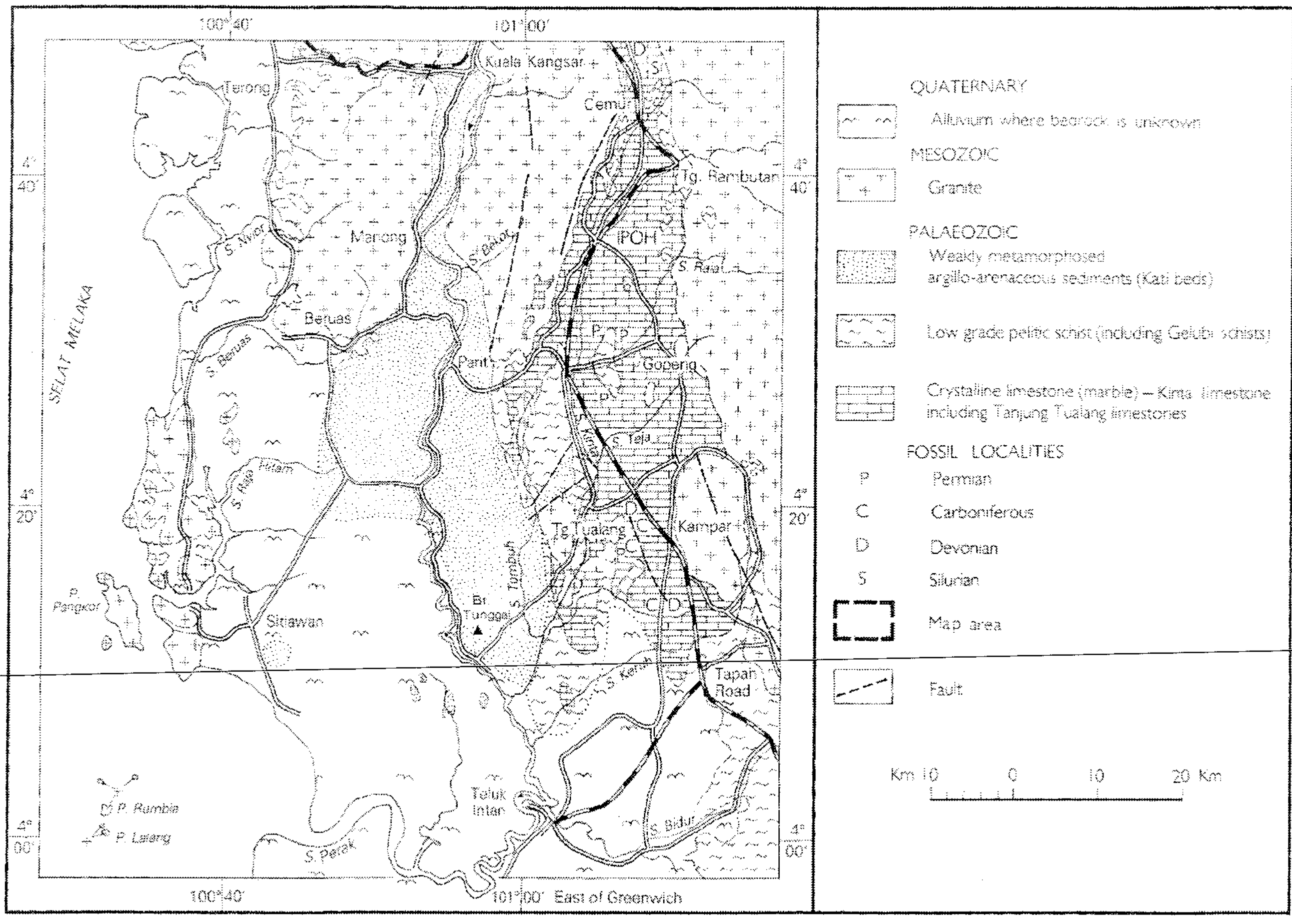

Figure 2.13: Geology of Lumut and Teluk-Intan area, from Wong (1991)

2.3.7 Depositional environment interpretation (based on sedimentary features)

- **Interpretation of Kinta Valley depositional environment by Ingham and Bradford (1960).**

In the Kinta Valley during the Paleozoic, carbonate sedimentation took place in a clear sea. However, these dominant limestone depositions were interrupted by occasional influx of terrigenous clastics (muddy and sandy sediments) and these clastic sediments eventually consolidated to form shale and sandstone (Ingham & Bradford, 1960).

- **Interpretation of Kati Beds depositional environment by Foo (1990) in the Kuala Kangsar areas.**

Kati Beds consist of appreciable thicknesses of shale, which strongly implies that these beds were deposited at water depths not affected by wave motion. The sequences of shale and siltstone are characterized by fine-grained textures, laminated nature and show good sorting. These features correspond to a quiet system. The sediment of Kati Beds was probably deposited in quiet deep waters (Foo, 1990).

The interpretation of the depositional environment as presented here by Foo (1990) is not very convincing, some issues have not been discussed. The appreciable thicknesses of shale in itself does not necessarily mean deposition below wave base. He has not produced any evidence of no wave action e.g., from lack of wave formed structures. Moreover, he did not mention how deep was the water basin? i.e. shelf, slope or abyssal?.

- **Interpretation of Kati Beds depositional environment by Wong (1991) in Lumut and Teluk-Intan areas.**

The sediments of the Kati beds were probably deposited in moderately deep water, close to the eroding landmass. The absence of cross-bedding and traction-current structure does not support a fluvial or deltaic origin. The fine lamination in the shales and siltstones signifies deposition at a depth not affected by wave motion. The absence of flysch-type sedimentary structure suggests that a deep water pelagic origin is unlikely. The occurrence of graded beds and flute casts in exposures at Bukit Tunggal suggest the influence of turbidity currents.

The uniform size of the major detrital clasts and poor rounding of the clastic materials could perhaps indicate a paleoenvironment where sorting was rapid due to a brief period of abrasion. Such an environment could be found in the moderately deep water just beyond the deltaic areas. Therefore, the likely sites for the deposition of the Kati beds appear to be in the moderately deep water of a submarine slope, immediately beyond and south southeast of a deltaic area (Wong, 1991).

Wong (1991) concluded that, during the late Paleozoic, the Kinta Valley was essentially a stable marine shelf (sedimentary basin) or platform as indicated by the thick sequence of conformable carbonate and clastic sediments of Carboniferous to Permian age. Moreover, he suggested that the clastic units (Kati Formation) sedimentation took place contemporaneously with the deposition of the carbonate rock units (Tualang Limestone which is the southwestern extension of Kinta Limestone). Wong also believed that during the late Paleozoic the calcareous sedimentation were interrupted by argillaceous invasions from the deeper more rapidly subsiding flank from time to time.

Even if the interpretations of depositional environments of Kati Beds (Formation) by Wong (1991) are not supported by biostratigraphic analysis as discussed in section 2.4, it still provides useful information regarding the depositional setting.

- **Interpretation of Kinta Valley depositional environment by Pierson et al. (2009).**

In a recent study by Pierson et al. (2009) the paleo-depositional environment of the Paleozoic carbonate of the Kinta Valley is interpreted as being deposited on a broad relatively deep marine slope, dipping to the west (during late Paleozoic) as indicated by analysis of slump structures. Pierson et al. (2011) suggests that the slump folds formed during deposition rather than as the result of the tectonic deformation. Furthermore, it is noted that the slope is dipping to the west and has a North-South strike direction. The presence of thinly-bedded, laminated and micritic limestone implies deposition in a low energy environment. The common occurrence of chert layers and chert laminae further suggests that the limestone was deposited in relatively deep water.

The interpretation of the carbonate depositional environments of the Kinta Valley by Pierson et al. (2009, 2011) is consistent with previous interpretations e.g., Wong (1991). However, they argue that "the broad platform" of these Paleozoic carbonates deposits (which include the clastic deposits) extend laterally to the eastern part of Peninsular Malaysia. This finding conflicts with the plate tectonic models of Peninsular Malaysia as discussed in section **4.3.**

- **Provenance (sediment source)**

The results of petrographic analysis showed that the sandstones are compositionally mature with high quartz/feldspar ratios which probably indicate that these deposits were subjected to significant chemical weathering at the source area or depositional site. The high chemical maturity coupled with the predominant suite of a well-rounded resistate zircon in the heavy minerals would suggest derivation from pre-existing sediments. Moreover, the flute cast shows a current direction towards the north-northwest. Therefore, it appears that the source areas were located to the north-northwest of the depositional site (Wong, 1991).

2.4 Paleozoic Hydrocarbon Plays in Malaysia

Hydrocarbon exploration activities in Peninsular Malaysia focused mainly on the Tertiary Formations. So far, commercial oil and gas comes chiefly from Tertiary deposits, which are located almost entirely offshore in the Malay basin, with the exception of a small sub-commercial oil discovery, Rhu, in the Penyu Basin (Tan, 2009).

The Tertiary rocks of the offshore Malay Basin province are made up of a complex of half grabens that were filled by lacustrine shales and continental clastics. These deposits were overlain by clastics of a large delta system that covered the basin (Bishop, 2002).

Two main Tertiary petroleum systems have been identified by Madon et al. (2006):

1) The Oligocene-Miocene Lacustrine Total Petroleum System (TPS), with lacustrine shale source and reservoir rocks.
2) The Miocene-Coaly Strata Total Petroleum System (TPS) with coal and coaly shale source and fluvial, deltaic, nearshore marine and offshore marine bar reservoirs.

There is spatial overlap between the Oligocene-Miocene Lacustrine TPS that has a lacustrine signature and the Miocene-Coaly Strata TPS that has a coaly signature (Madon et al., 2006; Bishop, 2002; Tan, 2009).

The stratigraphy of the Malay Basin is known by letters. Madon et al. (1999) identified the Groups L and K lacustrine shales (Upper Oligocene-Lower Miocene), and Groups I and H fluvio-deltaic shales and carbonaceous/coaly shales (Lower-middle Miocene) as the main petroleum source rock intervals for the Malay Basin. Deeper units such as sediments from Group M and pre-Group M (syn-reft) sediments are also believed to contribute to the petroleum systems.

Hydrocarbons are trapped in Middle to Late Miocene transpressional folds, anticlines, and some stratigraphic traps. These petroleum systems sealed by local and regional shale units, as well as sealing faults (Figure 2.14). Intraformational seals of overbank and transgressive shales seal individual channel sandstones and marine shales encase some nearshore marine sandstones (Bishop, 2002).

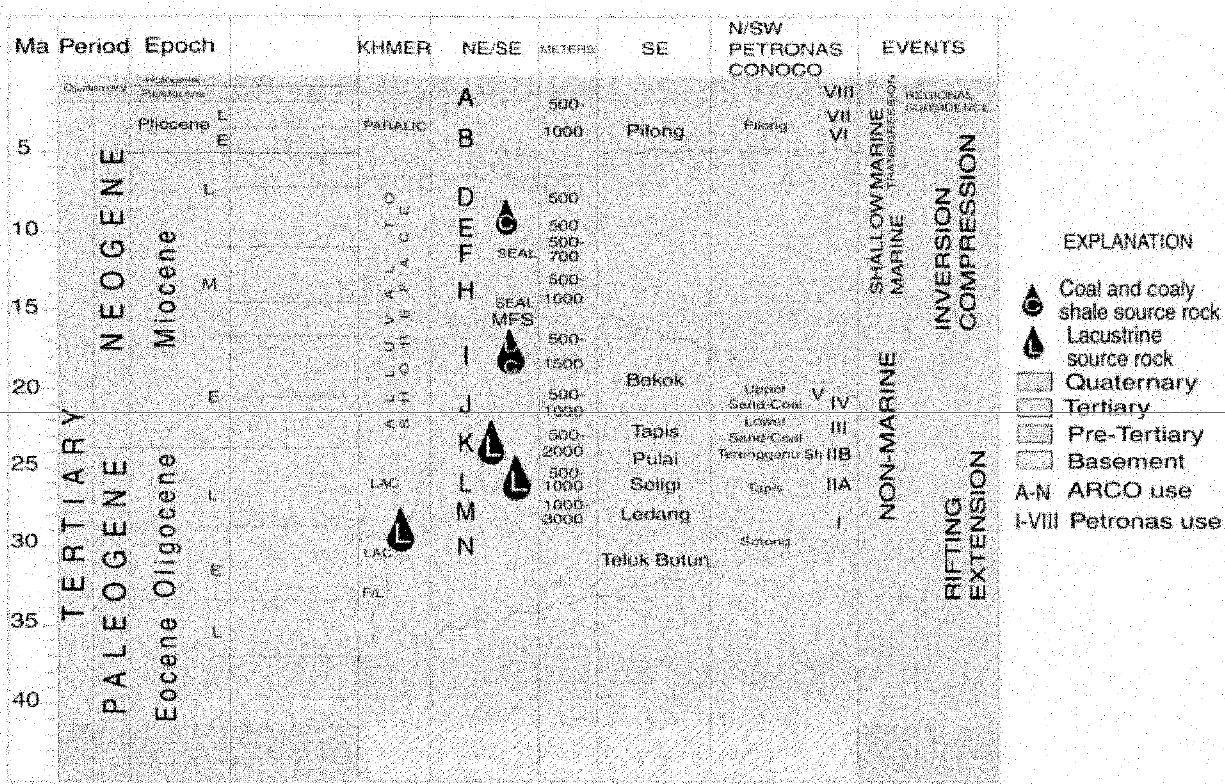

Figure 2.14: Malay Basin composite stratigraphy from Bishop (2002).

In the past several years, significant discoveries were made in Malaysia in Sabah, Sarawak and Malay Basins. The new discovery include novel play-types such as fractured basement, and new exploration concepts regarding carbonate pinnacle reef buildups and clastic turbidite fans. These discoveries were made in shelfal shallow waters as well as in deepwater environments.

Recent discoveries have been made in fractured basement rocks in the southwestern part of the Malay Basin. The Anding Utara-1 fractured basement oil discovery made in 2005, this exploration well penetrated an oil column of about 220m in metamorphic rocks (Shahar, 2005).

This discovery has confirmed the fractured basement play, as well as it indicates the possibility of having hydrocarbon accumulations in older rocks.

Furthermore, it opens up new frontier of untested basement plays and gave the impetus to pursue a similar play type in the Penyu Basin, where the basement is mainly fractured metamorphosed basalts and weathered tuffs (Fanani et al., 2006; Tan, 2009) (Figure 2.15).

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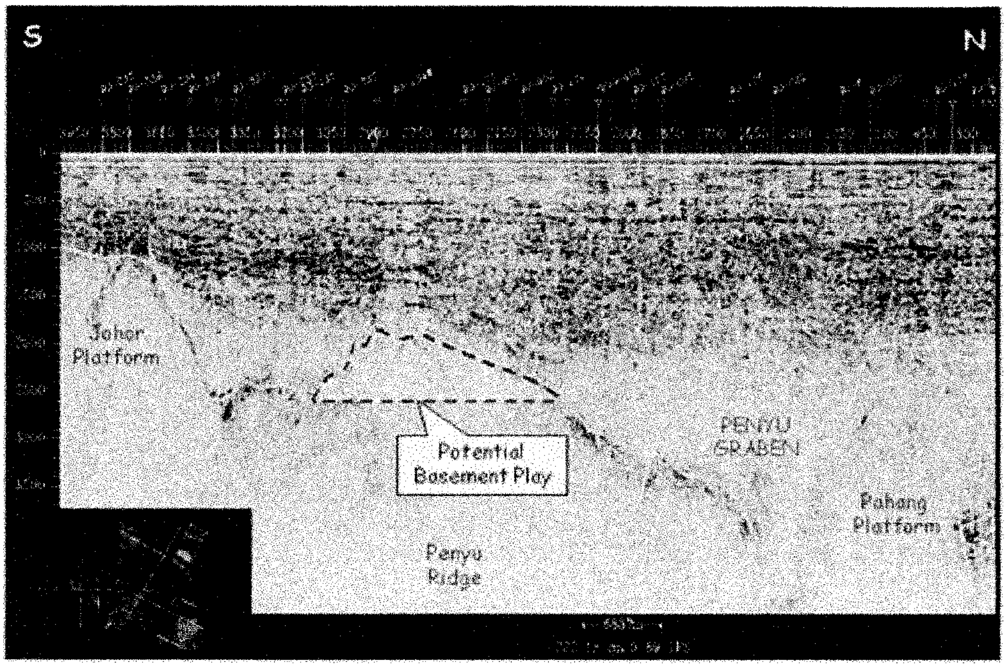


Figure 2.15: Interpreted seismic profile through the Penyu Basin, potential basement play is indicated by area in the red shape, from Fanani et al. (2006).

Based on results from fieldwork by Liew et al. (1996) there is a suggestion of a possible pre-Tertiary petroleum system (Tjia, 1999b). Initial observation of the Paleozoic sedimentary sequences in the Kinta Valley suggests the possible presence of elements of a Paleozoic petroleum system. The play (carbonate system) has been successfully proven in a few places but is still largely underexplored, mainly because little is known of the Paleozoic sequence at a regional scale and because the pre-Tertiary is commonly poorly imaged on seismic (Pierson et al., 2009)

Although a Paleozoic hydrocarbon system is still speculative (?), the possibility cannot be ruled out (Tjia, 1999b; Pierson et al., 2009).

From the paleogeographic reconstruction of the Paleozoic deposits in Peninsular Malaysia, Pierson et al. (2009) suggested that a potential new carbonate play may lie unexplored east of peninsular Malaysia (Figure 2.16).

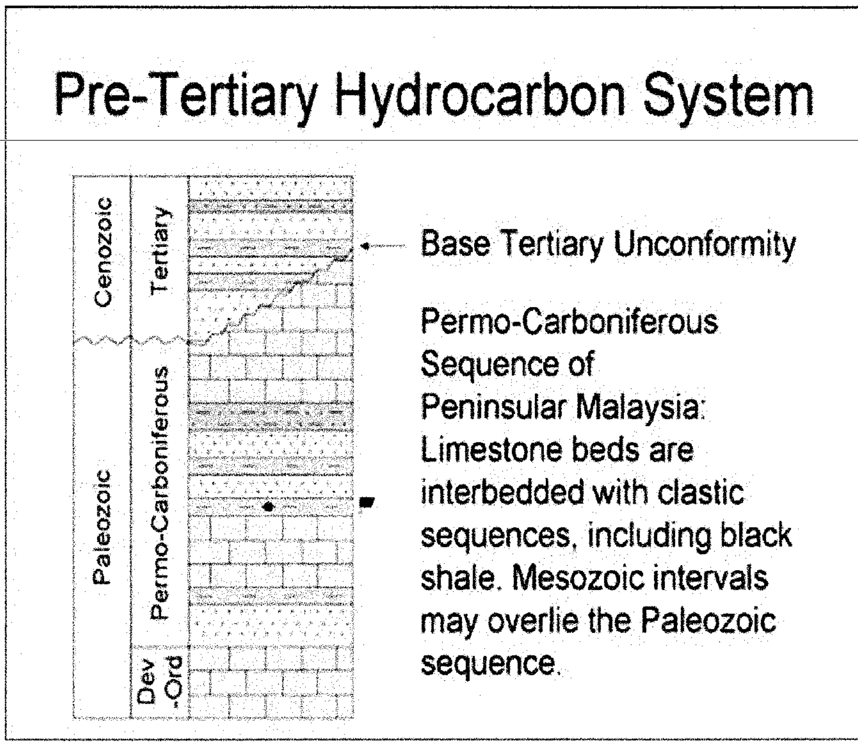


Figure 2.16: Schematic stratigraphic column showing the various elements of a hydrocarbon system as observed in the Kinta Valley. From Pierson et al. (2009).

Paleozoic deposits of Peninsular Malaysia (Kinta Valley) may encompass all the elements of a Petroleum system:

1) The black carbonaceous shale, which forms part of the Paleozoic clastic sequences in the western part of Peninsular Malaysia, is rich in organic matter. Samples collected at one of these outcrops have a measured (TOC) Total Organic Content (> 6%), making it a very good source rock.
2) The carbonates (shallow marine limestones in the eastern part of Peninsular Malaysia and offshore in the Malay Basin) and the thick clastic sequences (sandstone layers Permo-Carboniferous age in the western part of Peninsular Malaysia) may contain potential reservoir intervals.
3) The pre-Tertiary structural events may have created traps that would be offset from Tertiary traps. Structural and possibly stratigraphic traps and even "buried hills" traps may be present.
4) Clay and shale layers within the clastic sequences could act as intraformational seals. It is also possible that the base Tertiary unconformity has regional sealing capacity.

Potential source rock and sealing lithologies exist in the Paleozoic clastic sequences of the Kinta Valley (the western part of Peninsular Malaysia). Initial results of current investigations into Paleozoic carbonates suggest the presence of favourable potential reservoir lithologies in the eastern part of Peninsular Malaysia and offshore in the Malay Basin. However, it is uncertain whether these elements (in western part of Peninsular Malaysia) extend over the Paleozoic carbonate platform areas to the east of the Peninsular Malaysia, in the western part of the Malay Basin where an effective Paleozoic hydrocarbon system has a better chance to be found.

Based on the positive results from drilling of petroleum accumulations in the Anding Utara-1 oil discovery in metamorphic rocks in SW Malay Basin (Shahar, 2005), plus the fact that this fractured basement play involves reservoir rocks that are of Cretaceous age or older, all these clues point to the possible existence of hydrocarbon accumulations in older rocks (pre-Tertiary).

As part of an ongoing research effort is to look at older and deeper petroleum source rock intervals (Paleozoic and Mesozoic) that could have generated hydrocarbons earlier that subsequently accumulated in older and deeper reservoir intervals.

Gou et al. (2011) conducted a geochemical outcrop analogue study in Peninsular Malaysia to evaluate the potential of older Paleozoic and Mesozoic petroleum source rocks, and to see if any organic-rich intervals from the Paleozoic or Lower Mesozoic could have contributed to earlier hydrocarbon generation.

This recent work has focused on the geochemistry of outcroping Paleozoic and Mesozoic sedimentary rocks from NW Peninsular Malaysia, mainly the Black Shales of Kubang Pasu formation (Beseri, Perlis) and Mesozoic age rocks from Pahang in the central part of Peninsular Malaysia (Tembeling Group and Semantan formation).

The sediments from Paleozoic and Mesozoic sedimentary rocks were analyzed by means of SAR (Source Rock Analyzer), organic contents petrologicaly and GC-MS (Gas chromatography-mass spectrometry) geochemical methods.

Preliminary results of geochemical characterisation of 7 Paleozoic and Mesozoic samples (onshore in Peninsular Malaysia), showed that the black shaels of the Kubang Pasu Formation (Beseri, Perlis) are interpreted to be of Permian age and the type of the organic matter are predominately marine.

The total organic carbon (TOC) content ranged from poor to moderate (1.07 to 1.32 wt per cent). The Hydrogen Index (HI) at present day (mg HC/g TOC) is 10 to 92. The thermal maturity at present day is over mature and possibly the hydrocarbon could have generated oil previously.

On the other hand, samples from the Mesozoic rocks of Central Pahang (Tembeling Group and Semantan Formations) generally showed high TOC values up to 4.43 wt per cent. In Mesozoic shales the type of the organic matter is of terrigenous origin with a total organic carbon (TOC) content up to 4.43 wt per cent in Mesozoic shales. The Hydrogen Index (HI) at present day (mg HC/g TOC) is up to 57. The thermal maturity at present day gas window is over-mature. The hydrocarbon could have generated gas formerly. They concluded that, two different types terrigenous and marine are expected from these source rocks analogues.

Geochemical analysis showed organic-rich, high thermal maturity and signs of remaining hydrocarbon potential. Geochemical analyses suggest that Paleozoic and Mesozoic sedimentary rocks from Perlis and central Pahang do exhibit the presence of hydrocarbons.

2.5 Fundamental Concept of Geology as Applicable to Seri Iskandar

The purpose of this section is to review the literature on some basic geological concepts and techniques which are applicable in this study. Moreover, we have provided a detailed summary for literature related to hydrocarbon plays.

2.5.1 Sedimentary Environments

Perry and Taylor (2007) define environmental sedimentology as *"the study of the effects of both man and environmental change upon active surface sedimentary systems,"* and consequently *"the study of how both natural and anthropogenic inputs and events modify the production and accumulation of the physical and biogenic constituents of recent sedimentary deposits"*. In other words, a sedimentary environment is a geographic setting where sediments can accumulate, and examples include deserts, river valleys, lakes, and deltas etc. (Table, 2.1).

Terrestrial	Alluvial fan Rivers and their floodplain
Marginal-Marine	Deltas Alongshore sand bodies (beaches, barriers, cheniers)
Marine	Shelf Submarine fans- turbidites - Abyssal plains

Table 2.1: Major environment of deposition of clastic rocks (Walker 1979, 1984).

Each of these environments is characterized by a distinctive set of geological processes and environmental conditions. These geologic processes include physical and/or chemical and/or biological conditions (Pettijohn, 1975).

1) **Physical parameters** of a sedimentary environment, e.g., the water depth, velocity of depositing currents, direction of current flow, persistence of currents, direction and variation of wind, wave and flowing water, climate and weather.
2) **Chemical characteristics** of an environment e.g., the geochemistry of the rocks and the composition of waters (temperature, salinity, acidity or basicity (pH), oxidation-reduction potential (Eh), and pressure).
3) ~~**Biological processes** e.g., fauna and flora that populate the setting.~~

The environment of deposition and the characteristics of sedimentary rocks (mineral composition, grain size, shape and structures etc.) can be determined or defined by geologic processes (physical, chemical and biological) whereby sediments are accumulated together with the nature of the transporting agent and the source area (Pettijohn, 1975; Nichols, 1999).

- **Sedimentary Facies**

The term facies has multiple meanings and can be used not only as a descriptive term but also as an interpretive term.

Bates and Jackson, (1980) defined Facies as the aspect, appearance, and characteristics of a rock unit, usually reflecting the conditions of its origin; especially as differentiating it from adjacent or associated units (lateral or vertical). Sedimentary facies can also be defined as bodies of sediment recognizably different from the adjacent sediment deposited in a different depositional environment (Selley, 1985; Reading, 1996; Boggs, 2001). The concepts of sedimentary environments and sedimentary facies are summarized in (Table, 2.2).

CAUSE → EFFECT

Processes
Physical, Chemical, Biological → SEDIMENTARY ENVIRONMENT (Erosional, Non-depositional, Depositional) → SEDIMENTARY FACIES (Geometry, Lithology, Sedimentary Structures, Palaeocurrents, Fossils)

Table 2.2: Relationship between the sedimentary environment and sedimentary facies (Selley, 1985).

Facies is defined and characterized on the basis of their properties, such as lithology, grain size, colour, bedding, composition, texture, fossils content and dominant sedimentary structures. Moreover, it can be sub-divided into sub-facies or grouped into "an association of facies". Facies associations are groups of facies that occur together and are considered to be genetically or environmentally related, such as fining and coarsening-upward successions of facies, which indicate shifts in environmental conditions (Reading, 1978, 2001).

Different types of Facies:

1) **Lithofacies**: descriptive term, based on petrologic characters and lithologic features such as composition, mineralogy, grain size, bedding characteristics, and sedimentary structures.
2) **Biofacies**: based on fossil content.
3) **Ichnofacies**: based on a general trace fossil assemblage.
4) **Seismic facies**: interpreted in terms of characterisation based on seismic amplitude, reflection and continuity.

The genetic relationship between depositional processes and rock properties in addition to detailed studies of modern environments are commonly used in the interpretation of ancient processes and environments. In general, sedimentary environments can be defined and distinguished from other areas on the basis of its distinct physical, chemical and biological characteristics and these characteristics and conditions can also be used to construct facies models for each major depositional environment.

A facies model is a conceptual scheme linking the evolution of a particular sedimentary environment and the particular vertical profile and facies assemblages which records this evolution (Pettijohn, 1975). Walker (1979) defined facies model as a summary of specific sedimentary environments.

Facies model concepts have been used extensively in classifying and interpreting ancient depositional environments. A number of models can be used to recognize and interpret clastic depositional environments e.g., Turbidite facies models of Bouma, 1982, and the alluvial models of Rust, 1978 and delta models of Miall, 1977. The problems and successes with facies models characterisation have been discussed in detail elsewhere (Reading, 1978; Walker, 1984).

- **Methods for environments diagnosis**

Many different techniques can be used to determine the dispositional environments of the sedimentary rocks. These vary considerably according to whether the study is based on surface or subsurface information.

In surface outcrop-based studies, the sort of lithology, sedimentary structures, facies patterns and fossils hold many important clues to its depositional processes and environment. Therefore, these criteria can be used to diagnose and recognize depositional environments (Pettijohn et al, 1973; Walker, 1979; Scholle et al., 1982; Tucker, 2003). Depositional environments of a facies may be deduced from rocks at the surface using the five defining parameters of geometry, lithology, sedimentary structures, palaeocurrents and fossils (Selley, 1978, 1985).

1) **Geometry**

A geometry of sedimentary facies is a three dimensional body of depositional units (rocks) having geometrical shapes that reflect it pre-depositional topography, the geomorphology of the depositional environment and its post depositional history (Selley, 1985). The Geometry of sedimentary facies is not a diagnostic criteria for sedimentary environment interpretation, since similar facies geometry could be produced in several other environments e.g., channels could be fluvial, deltaic, tidal or submarine). However, tracing the geometry of a sedimentary unit may provide information on lateral continuity, thickness and changing in characters.

2) **Lithology**

The lithology of clastic sediments is not only a product of the environment in which it was deposited, but also its transportation processes and source rock (provenance). The measurable lithologic features of a sedimentary facies, such as mineral content, grain size, sorting and texture can give valuable indication to its depositional processes and environment e.g., energy level or conditions.

Moreover, there are a number of studies using geochemical approaches that have shown that clay minerals have great potential in environment diagnosis (Selley, 1978).

3) **Sedimentary structures**

The sedimentary structures found in sedimentary rocks are the most commonly used diagnostic criteria (by geologists) for recognizing their depositional setting because they cannot be recycled (in situ). Moreover, they provide further valuable clues to the environment of deposition. Sedimentary structures reflect depositional processes and conditions associated with the deposition (physical, biogenic, or chemical processes) such as, flow orientation and conditions of the current which generated them, water depth and the energy level and the current velocity. Sedimentary structures are very diverse and many can occur in almost any lithology and they are arbitrarily divided into primary and secondary classes (Table 2.3).

Primary structures are those generated in sediment during or shortly after deposition and result mainly from the physical processes such as, current and waves (e.g., ripples, cross-bedding and slumps).

Secondary sedimentary structures are those that formed sometime after sedimentation. They result from essentially post-depositional chemical processes, such as those which lead to the diagenetic formation of concretions (Selley, 2000).

Most sedimentary structures can be studied only in outcrops and cores therefore the microscopic study is largely inappropriate (Pettijohn et al., 1987). There are two basic approaches to observe sedimentary structures. The first approach is to pretend the outcrop is a bore hole and to measure a detailed sedimentological log while the second approach is a two-dimensional survey of all, or a major part, of the outcrop (Selley, 1988).

Primary (Physical)	Inorganic	Fabric	Microscopic
		Cross-bedding, ripples, etc	
	Organic	Burrows and trails	Megascopic
Secondary (chemical)	Diagenetic	Concretions, etc.	

Table 2.3: A classification of sedimentary structures modified after Selley (1988).

4) **Palaeocurrents**

Palaeocurrents can be defined as the study of ancient flow and is an interpretive criteria. However many sedimentary structures can be used to interpret palaeocurrents and determine the direction or orientation of flow which they deposited the sediment.

Paleocurrent analysis of a facies is an important criterion to diagnose the depositional setting for various other reasons such as:

1) provides the basis for mapping the palaeogeography of a sedimentary basin (paleogeographic reconstruction).
2) provides valuable indicators and directional data about the orientation of the sedimentary systems that aid to interpreting geologic setting and depositional environment.
3) used as a powerful tool for prediction of the geometry and trend of mineral deposit and petroleum reservoir characteristics in sedimentary rock.
4) yields information about the flow directions of rivers, longshore currents, sediment gravity flows, paleowinds and the direction of initial dip or paleoslope.
5) yields clues to the provenance of sediment supply.

The orientation of directional sedimentary structures is determined in the field with a Brunton® compass by taking measurements from as many different outcrops and individual beds as possible and practical. These paleocurrent data are commonly plotted on the rose diagram or stereonets. An individual sedimentary structure can indicate the ancient flow direction at geographic point and at that instant in time. However, in regional scale analysis statistical populations of sedimentary structures are needed (Selley, 1988; Boggs, 1995).

5) **Fossils**

Fossils are the remains, traces or imprints of ancient organisms (such as bones or shells) that have been preserved within the rock record (e.g., sand and mud). Fossils include trace fossil or body fossil and can be grouped into macrofossils, microfossils and trace fossils. Geologists have relied heavily on fossils as key indicators of geologic time (relative age) as well as depositional environment. As they reflect the ecological and physical processes at the time of deposition such as ancient water depths, salinity, temperature, water depths and energy and turbidity of ancient oceans. Interpreting paleoenvironments with fossils (found within sedimentary units) is aspects considered to be highly relevant to paleontology. The study of trace fossils is called "Ichnology". Trace fossil assemblages can be divided according the palaeoenvironmental scheme into a number of ichnofacies named after a characteristic trace fossil. The ichnofacies indicate a particular sedimentary facies and can be identified on the basis of its trace fossil assemblage (Figure 2.17).

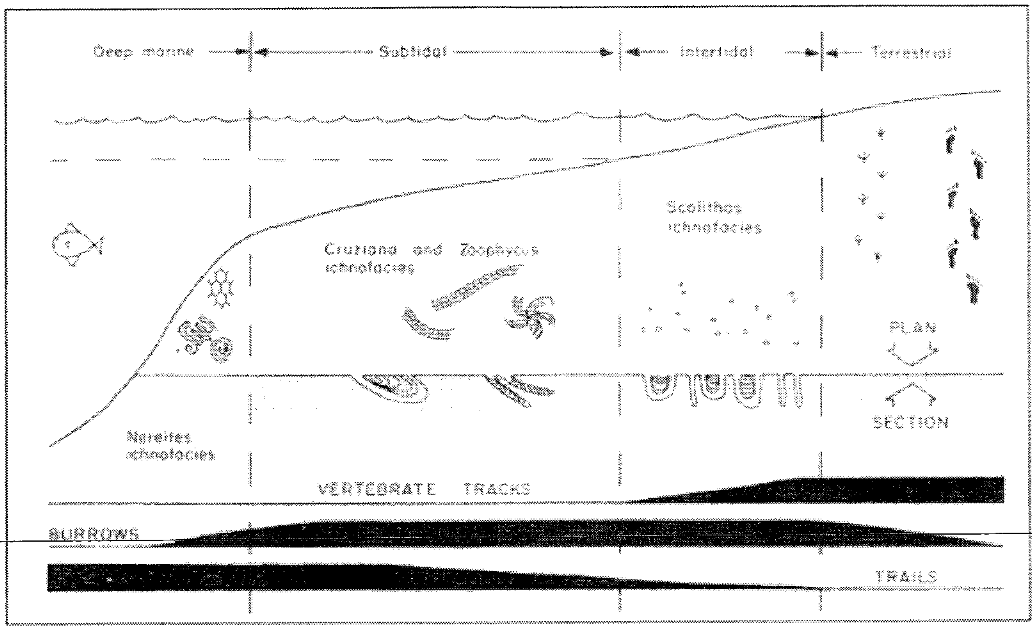


Figure 2.17: Relationship between ichnofacies and environments (Seilacher, 1964; Heckel, 1972; Selley, 1988).

2.5.1 Hydrocarbon Plays

A play is referred to as a family of pools and/or prospects and leads (accumulations and/or potential accumulations) that share common geological characteristics and history of hydrocarbon generation, migration, reservoir development, and trap configuration (Reinson et al., 1993; Magoon & Beaumont, 1999).

Hydrocarbon Plays can be further subdivided into two major types:

1) Established plays are demonstrated to exist by virtue of discovered pools (due to the discovery) with established reserves (mature and or immature).
2) Conceptual plays are those that have no discoveries or reserves (do not contain discovered petroleum reservoirs), but geological analyses indicate the possibility of their existence (geologically possible).

Speculative play is a type of conceptual play that has insufficient geological information for quantitative analyses. Therefore, these plays are only described qualitatively. Often, there is some doubt whether these plays actually exist in the area of interest (Osadetz et al., 2005).

Three common methods used in analysis of hydrocarbon plays:

1) Petroleum System Analysis.
2) Statistical Methods e.g., the discovery process model PETRIMES (Canadian system)
3) Drilling exhaustion Analysis.

Petroleum System Analysis method is a theoretical exercise that is often used in very immature basins that have very little physical data. Regional geological studies including surficial mapping and a few wells, and regional-scale geophysical interpretation are needed to define petroleum system and the types of traps. Petroleum System Analysis method is commonly used in the evaluation of the conceptual plays due to the absence of any discovered pools with established reserves. Moreover, they are also often characterized by high risk associated with source maturity, migration paths (carrier beds).

Conceptual play analysis (**Speculative play**) was applied exclusively in this study due to the absence of any discoveries (oil or gas) or reserves. Since, this study is aimed at reducing uncertainty involved in the analysis of place of conceptual plays and to develop a basic understanding of reservoir potential.

2.5.1.1 Reservoir potential assessment

Geological analysis of a hydrocarbon system often requires surface outcrop studies, especially in the absence of the subsurface data (wells and seismic). One of the main objectives of this study is to provide original sedimentological, porosity-permeability and textural parameter data to the study of these clastic sediments in order to define reservoir quality and to provide a preliminary assessment of the reservoir potential of the Paleozoic clastic sequences in Seri Iskandar.

Predicting subsurface porosity and permeability from outcrops is a key challenge for hydrocarbon exploration and development when there is complete absence of any subsurface data or only a little subsurface data are available. Samples from outcrops may provide an important source of data for the study of correlative reservoirs and provide an opportunity to observe sedimentary structures, lateral facies changes, and three dimensional spatial relationships of correlative subsurface rocks (Maravelis & Zelilidis, 2012). Outcrop-based samples also help in understanding the burial history and the role of different diagenetic modifications on reservoir properties, which lead to the prediction of porosity and permeability of subsurface reservoirs (Tobin, 1997).

To aid the assessment of the potential subsurface porosity and permeability and predict the subsurface reservoir quality in this outcrop-based study (where only surface outcrops data are available), the reservoir potential of the sandstone beds exposed at Seri Iskandar was assessed based on data available from sedimentological study, core analysis and petrographic studies using a systematic decision tree based procedure proposed by Tobin (1997) (Figure 2.18 and Table 2.4).

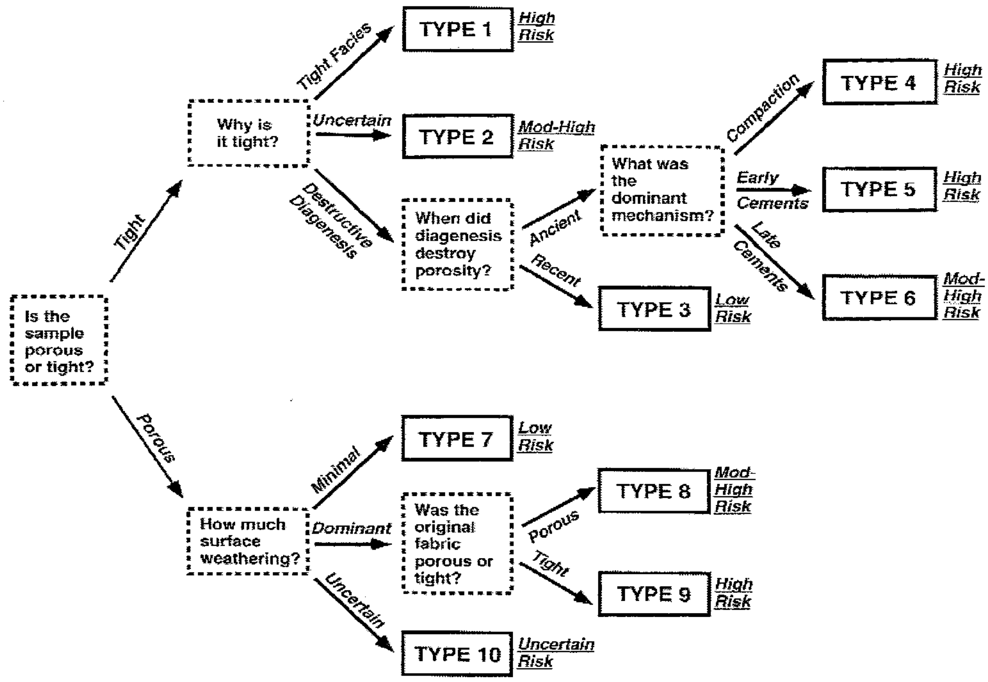


Figure 2.18: Decision-tree flow diagram used to evaluate the degree of exploration risk from the study of outcrop materials. Outcrop samples are classified into ten rock type categories based on their potential as subsurface reservoir facies. From Tobin (1997).

Note that outcrop-based prediction of subsurface reservoir quality has certain limitations, including differences in diagenetic history and pore system evolution between surface and subsurface samples. The fact that ancient or recent diagenesis events such as leaching, cementation and sediment infill, etc. may enhance or destroy porosity and permeability that occurs in the subsurface (Fraser & Allen, 2007; Tobin, 1997). Therefore, the results from this analysis will be used as an approximation of subsurface reservoir quality.

Category	Name	Porosity	Typical Lithologies	Risk Assessment
Type 1	Tight depositional facies	Tight	Micritic limestone, marl and shale, sandy limestone, micritic dolomite, argillaceous siltstone, sandstone, or conglomerate	High risk unless fracturing, dolomitization, or porosity can be predicted
Type 2	Uncertain depositional facies	Tight	Recrystallized sparry limestone, some coarse, nonplanar dolomite, some quartz-cemented or metamorphosed quartz sandstones	High risk as above, unless original fabric can be determined
Type 3	Recent pore destruction	Tight	Originally porous sandstones and conglomerates, lime grainstones or packstones tightly cemented by recent weathering by-products	Very low risk for prospects shallower than pre-outcrop burial depth; variable risk for deeper prospects
Type 4	Dominantly compacted	Tight	Originally porous, but now tightly compacted sandstones, conglomerates, or nonmicritic carbonates	Very high risk for prospects that are as deep as pre-outcrop burial depth unless early overpressuring, rim cementation, or dissolution can be predicted
Type 5	Early near-surface cemented	Tight	Originally porous sandstones and conglomerates, lime grainstones, or packstones tightly cemented by ancient near-surface cements	High risk unless lateral cement pinchout or cement dissolution can be predicted
Type 6	Late burial cemented	Tight	Originally porous sandstones and conglomerates, lime grainstones, or packstones tightly cemented by ancient burial cements	Moderate to high risk unless lateral pinchout, dissolution, or diagenetic traps can be predicted
Type 7	Recent weathering minimal	Porous	Any porous lithology whose pore system is inherited from the subsurface (minimal recent weathering)	Very low risk for prospects shallower than pre-outcrop burial depth; variable risk for deeper prospects
Type 8	Weathered; depositional fabric porous	Porous	Originally porous depositional fabrics rendered tight by compaction or cementation, but leached by recent weathering	Moderate to high risk facies; risk assessment equivalent to Type 4, 5, or 6 as appropriate
Type 9	Weathered; depositional fabric tight	Porous	Originally tight depositional fabrics that have been leached by recent weathering processes	High risk facies; risk assessment equivalent to Type 1 lithofacies
Type 10	Recent weathering uncertain	Porous	Any reservoir lithology whose pore system contains appreciable amounts of secondary porosity of uncertain origin	Uncertain risk, but generally higher for increasing secondary porosity component

Table 2.4: Summary of outcrop categories and associated reservoir quality risks. From Tobin (1997).

CHAPTER 3

METHODOLOGY

3.1 Introduction

The primary purpose of this chapter is to describe the different methods and techniques that have been used in this study in order to achieve its main objectives. The choice of methods depends on the scope of study and availability of data and materials.

The investigation methods were divided into:

1) Field Methods
2) Laboratory Methods

Fieldwork has been carried out by means of observation and description of rock outcrops and samples collection. Subsequently, the representative samples of sandstones were taken for laboratory analysis and the results were obtained from the use of different methods (field and laboratory works) interpreted and discussed to provide satisfactory answers to the problem statements.

3.2 Field Methods

Field work served as the primary source of obtaining geological data (data collection), and one of the two methods undertaken in this study to investigate the surface geology of Seri Iskandar. Prior to conducting the field work, handheld GPS and satellite imagery maps were used to locate and record the rock outcrops in Seri Iskandar (the study area). Fieldwork was conducted on four outcrops in Seri Iskandar. These outcrops have been selected for the study because they are fresh and provided good exposures of the various types of clastic rocks.

Each outcrop was alphabetically assigned a one-letter code in the order that the outcrop was visited. Outcrop locations are described in more detail along with their descriptions in the next chapter. Finally, the raw data that were obtained from the extensive field work were recorded in the field notes, field sketches, maps, tables, cross section and lithologs.

Fieldwork was broken down into six major tasks:

1) Outcrops observation and description
2) Structural study
3) Stratigraphic section measurement (lithologs)
4) Sample collection
5) Field photography
6) Mapping work and sketches

3.2.1 Outcrops Observation and Description

A detailed observation and description of the clastic outcrops in Seri Iskandar was conducted following the method by Tucker (2003). This description includes the study of six aspects of the sedimentary rocks namely:

1) Lithology
2) Texture
3) Colour
4) Sedimentary structures
5) The geometry and the relationship of the beds or rock units.
6) Fossils

Description of the outcrops began by dividing each outcrop section into intervals based on:

1) Predominant grain size
2) Bedding characteristics
3) Composition and colour of the rock

The bedding characteristics consist of thickness classified using the terminology from Boggs (1987), colour in general descriptive terms, variations in friability, presence or absence of sedimentary structures, and the natural stratigraphic contacts, the orientations to bedding shape, filling, and composition that makes up the texture of rock. Moreover, weathering and diagenetic processes such as compaction and cementation influence these clastic deposits.

3.2.2 Structural Study

The present faults and folds in the outcrops were studied and described. The dips and strikes were measured directly at the outcrops and recorded using a Brunton® compass.

3.2.3 Stratigraphic Section Measurement (lithologs)

Stratigraphic section measurement is essential to get information about bed thickness and it shows the relationships among various lithofacies (Compton, 1962; Tucker, 1996). The method used in measuring these sections was after the standard procedures given by Compton (1962), and in addition, to Tucker (1988). All of the following factors must be considered before deciding which measuring method to use:

1) The degree of details required
2) The physical nature of the terrain
3) The rock exposures

Each bed was studied individually at these sections and notes were made on bed continuity, variations in bed thickness, lithology and sedimentary structures. When possible, these measurements were taken. However, the aspect of structural complexities was taken into account.

3.2.4 Samples Collection

Sandstone samples were collected from selected locations that are considered as being representative and in those areas containing obvious facies changes or lithological changes (above and below the stratigraphic bedding contacts). A hand lens and visual comparator (an American/Canadian Stratigraphic visual grain-size comparator) were used to select samples composed mostly of medium to coarse sand. A total of 65 sandstone samples were collected from the four outcrops scattered in different locations in Seri Iskandar.

- 30 samples were sent to the Minerals and Geoscience Department Malaysia (JMG) and were made into thin sections for petrophysical analysis and diagenetic processes study.

- 25 hand samples were collected from the outcrops for examination in the laboratory.
- 10 surface core plugs samples were collected from all available sandstones in Seri Iskandar outcrops [A and D] using a portable rock core drills Pomeroy Model D026-C- BSS-1E bit, 1-inch core (Figure 3.1).

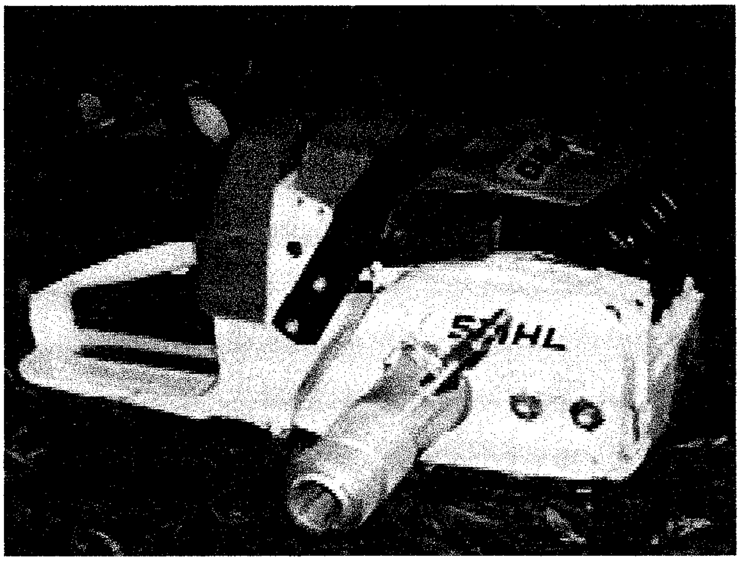


Figure 3.1: Surface core sampling with portable core sampler.

3.2.5 Field Photography

Field photography played a major part of data collection and was very useful during the process of interpretation. The sedimentology and structural features were covered by taking snaps at different locations in these four outcrops using a Nikon D80 digital camera.

3.2.6 Mapping Work

Geological mapping is the backbone of the field work. It illustrates the distribution of different rock types, the location of faults, folds and the orientation of other structural features. Moreover, it highlights the relations between lithology, structural style and other geologic features in the outcrops (Compton, 1962).

Before conducting the fieldwork, satellite imagery on the project area was studied to acquire basic information about the study area (outcrops). It also helped decide to select which

which outcrop needed to be visited. Finally, using geographic information systems (GIS), ArcMap the detailed geological maps of the study area were made after the fieldwork has been completed.

3.3 Laboratory Methods

Laboratory work is a crucial technique. It provides useful information which will help to get a clear picture of what have been observed and examined in the field work. Combining field work and laboratory analyses are significant in order to reach firm conclusions and achieve the main objectives of this study.

The various techniques which were applied in the laboratory include:

1) Thin sections study (Petrographic and mineralogy examination)
    a) Visual estimation of porosity and permeability
    b) Diagenesis study (e.g., Cementation, Compaction)
2) Core Analysis. Porosity and Permeability measurements on core samples (helium Porosimeter).
3) Paleontology. To search for microfossils (e.g., pollens in thin sections).
4) Digital photomicrography

3.3.1 Thin Sections Study (Petrography and mineralogy)

Petrography is a technique for examining rock samples under a microscope to obtain information about their texture, structure and composition (Scholle, 1979). After the collection of sandstone samples from the field, 30 selected representative samples were sent to the Minerals and Geoscience Department Malaysia (JMG) to be made into thin sections. A total of 25 petrographic thin sections were prepared, so that at least 10 thin sections was available from each outcrop. These thin sections samples were examined with transmitted and refracted light in a petrographic microscope, using a Microscope (BX51, Olympus) equipped with a CCD Camera (DP72, Olympus (Figure 3.2).

As a first step in textural examination of the thin sections, the percent abundance of framework grains, matrix and cement was estimated using the comparison chart for estimating percentage composition Terry and Chilingar (1955). The Wentworth grain-size scale and an American/Canadian Stratigraphic grain-size comparator were used to determine grain size. The sorting, roundness, and sphericity were estimated from visual comparators in Harrell (1984) and Powers (1953). Terry and Challenger's (1955) guide for visual estimation of porosity was used to determine porosity in each thin section. The results of qualitative abundances and descriptions of texture and mineralogy subsequently were recorded.

The sandstones were classified and identified based on their texture and mineralogical composition as observed in thin section, following classifications of and McBride (1963) and Folk (1980). Moreover, the effects of diagenetic processes such as compaction and cementation were determined.

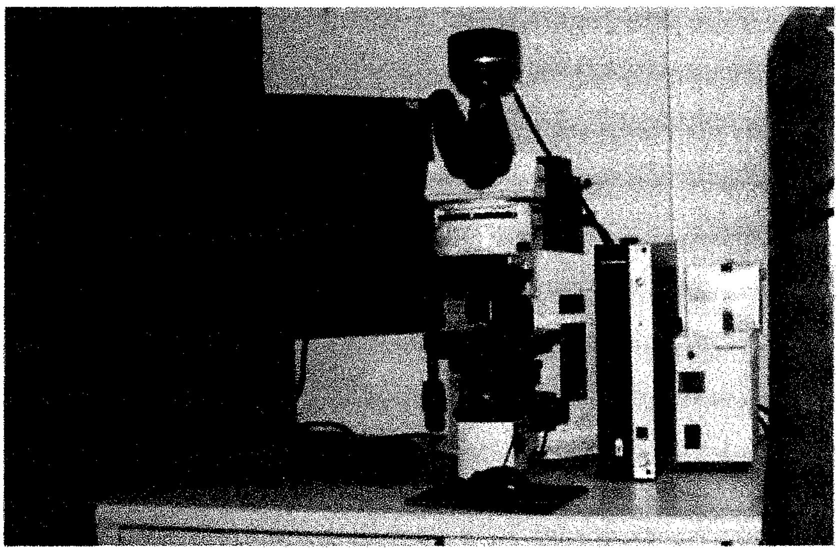


Figure 3.2: Olympus. BX51 Microscope with advanced digital micro imaging, DP72.

3.3.2 Core Analysis

Core analyses were performed in UTP on 10 core plugs samples to determine the porosity and permeability, using Helium Porosimeter Coreval-30® (Vinci Technology TM) based on an unsteady state (transient) method (Figure 3.3).

3.3.3 Paleontology

Palynology is the study concerned with evolution, morphology, and taxonomy of pollens and spores and their relative position of their occurrences in space and time (Selley, 2000). In order to provide age estimation for the clastic sequences of Seri Iskandar and determine their depositional environments, hand lens and other geological tools and equipment were used to investigate for plant remnants which can be found in some clay sequences.

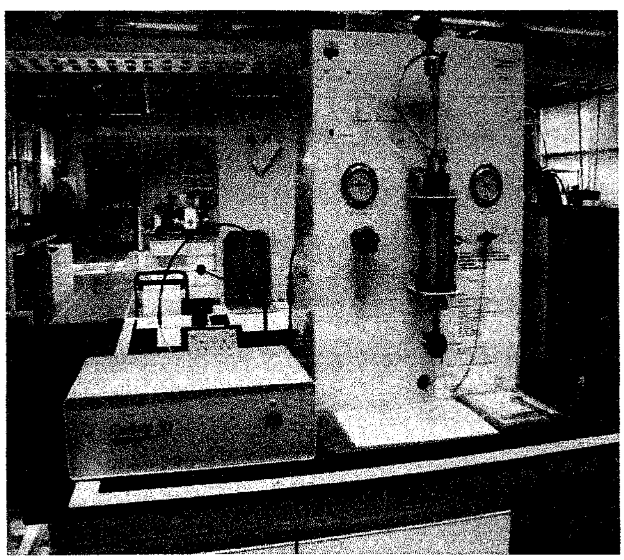


Figure 3.3: Helium porosimeter (Coreval 30® instrument) used for measuring porosity.

3.3.4 Digital Photomicrography

Photomicrography or microphotography is photography through the microscope. The digital photomicrography is an important approach to improve the observation and interpretation quality of the petrographic features. All thin sections were photographed digitally at high resolution to obtain high-quality images of sandstone samples by an attached Olympus digital camera (DP72, Olympus) using Olympus compound microscope (Model BX52) under Magnification range of x4, x10 and x20.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Field and description of outcrops

Field work was conducted on four outcrops in the Seri Iskandar area Perak (with a total thickness of ~785m) as shown in (Figure 4.1). These outcrops have been selected because they are fresh and provided good exposures of the various clastic rocks. The purpose of the fieldwork was to make a detailed sedimentological study, structural observations and collect samples for petrographic analysis, porosity and permeability analysis for reservoir potential and fossils for dating the rocks.

Four major dominant lithologies were recognized within the Seri Iskandar outcrops, including sandstone, siltstone, mudstone with thinly interbedded sandstones, siltstones and mudstones. These units are described in order of abundance observed in the field.

4.1.1 Outcrop [A]

Outcrop [A] is bounded by Coordinates 4°22'34" and 4°22'38"N, and 100°57'10" and 100°57'00"E (Figure 4.2). The rocks exhibit a general bedding strike of 325° and show high dip angles varying within the range of (45 to 80°) towards the East. The rocks generally consist of alternating beds of sandstone, mudstone and siltstone. Generally, these clastic beds have very steep dips, dipping almost vertically (Figure 4.3). Detailed section of the Outcrop [A] was measured; this section provided individual bed thicknesses, grain-size distribution, and sedimentary structures associated with the sandstone and mudstone beds. The total thickness of the beds measure about 260m as shown in (Figure 4.4).

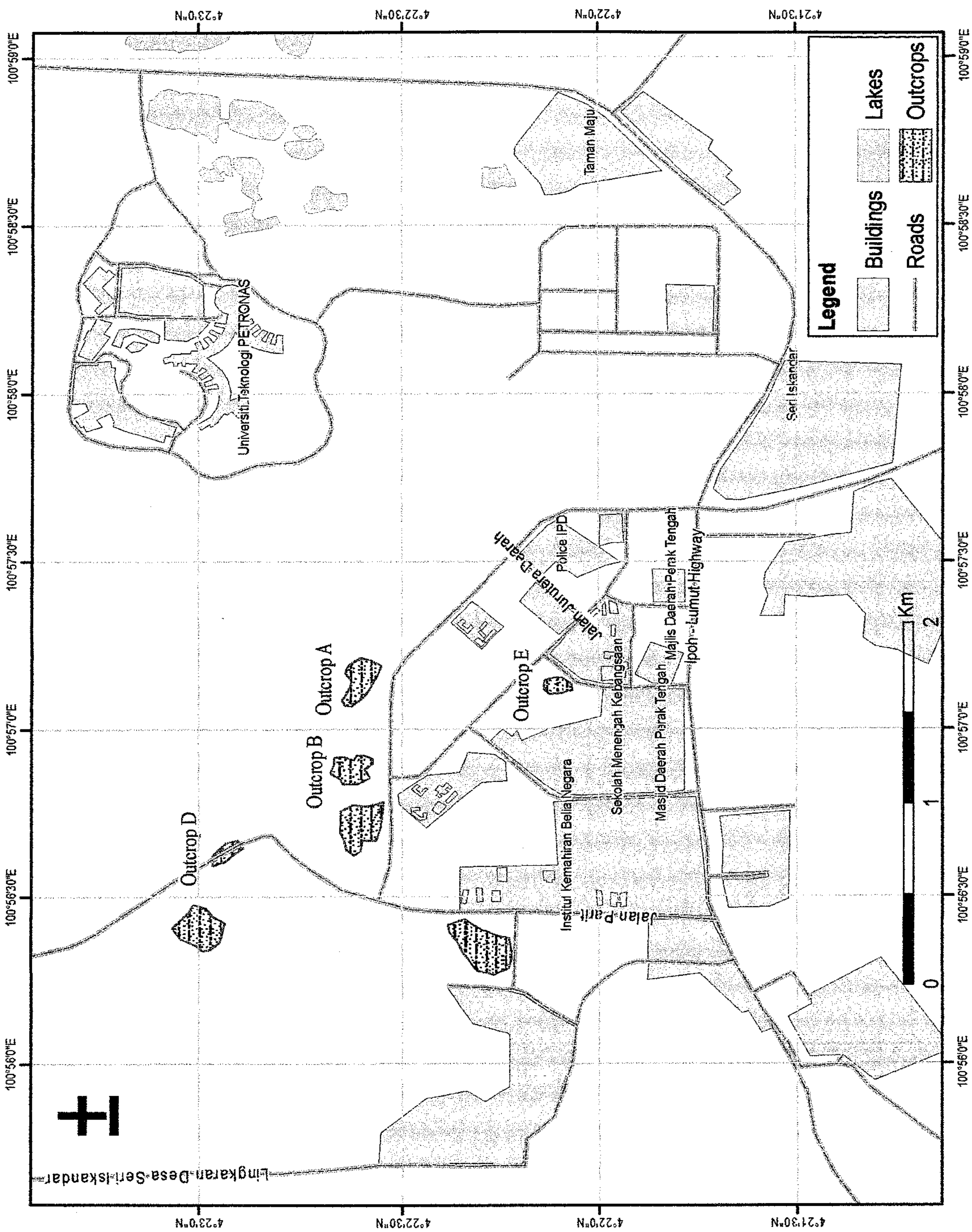


Figure 4.1: Map of the study area showing the location of outcrops of the Seri Iskandar. Each outcrop was alphabetically assigned a one-letter code in the order that the outcrop was visited.

Figure 4.2: Panoramic view from the outcrop [A], the largest clastic outcrop observed in Seri Iskandar area is approximately 260m (853 feet) long from the NW to SE. Note the overall irregular geometry of these units. This outcrop is marked by a distinct erosional surface, lithologies dominated by light grey to purple grey mudstones with minor thin sandstones yellow to brownish in colour.

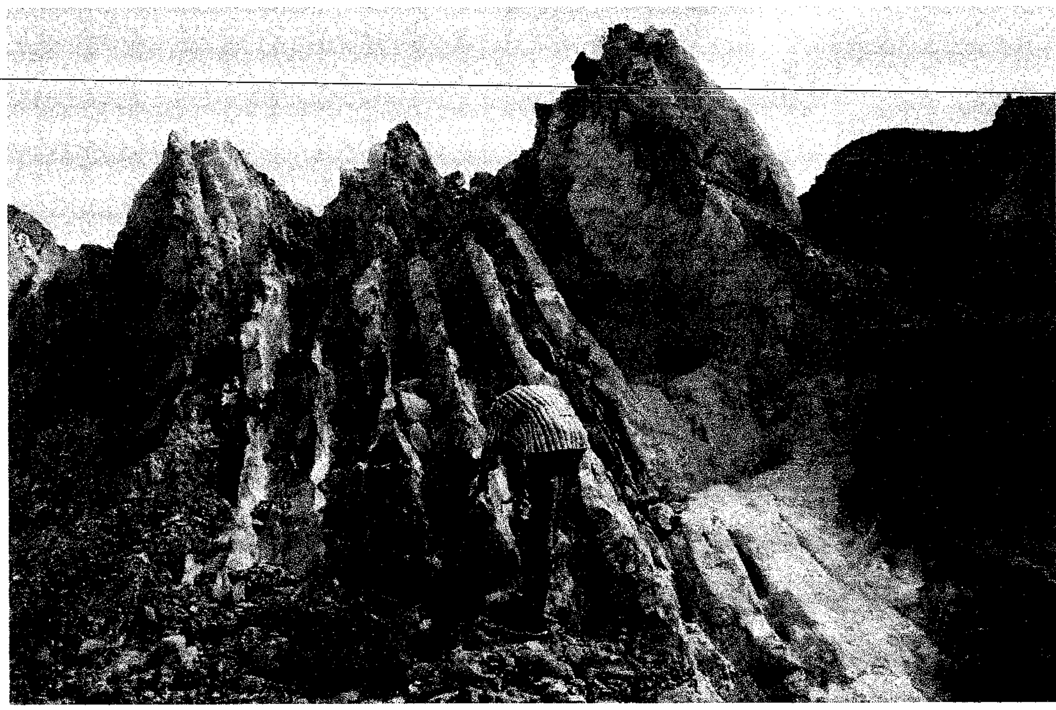


Figure 4.3: Shows alternating beds of sandstone, mudstone and siltstone 30m thick, these beds stacked relatively in an almost vertical position. These rocks indicate that the area has undergone has undergone tectonic processes which had tilted the beds.

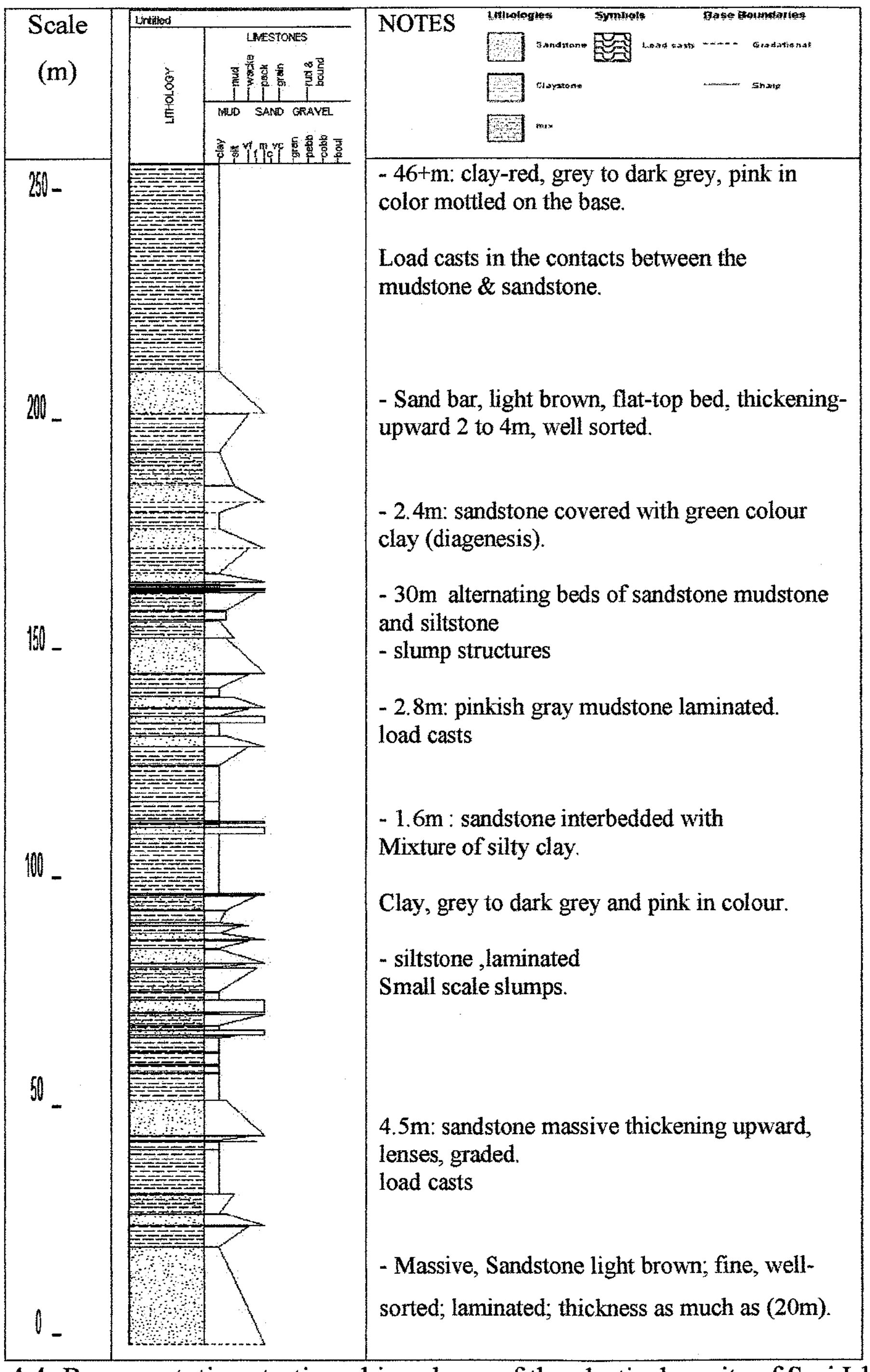


Figure 4.4: Representative stratigraphic column of the clastic deposits of Seri Iskandar outcrop [A].

1. **Sandstone beds**

Sandstone beds are found throughout the section, with thicknesses varying from a few centimeters to several meters (Figure 4.5). The beds are generally thick, varying between 5cm to 20m, hard when dry, very friable when moist in some part as a product of the tropical weathering. The quartz grains in the sandstone are rounded and well sorted. The high proportions of quartz grains indicate their mineralogical and textural maturity. The sandstone varies in colour from brown to yellow and this variability is dependent on the type of cement and diagenetic impact. Most of the sandstone beds are characterized by internal features including Liesegang rings caused by iron oxide staining, graded bedding, lamination, burrow tracks and fractures infilled with iron oxide (Figures 4.6 & 4.7).

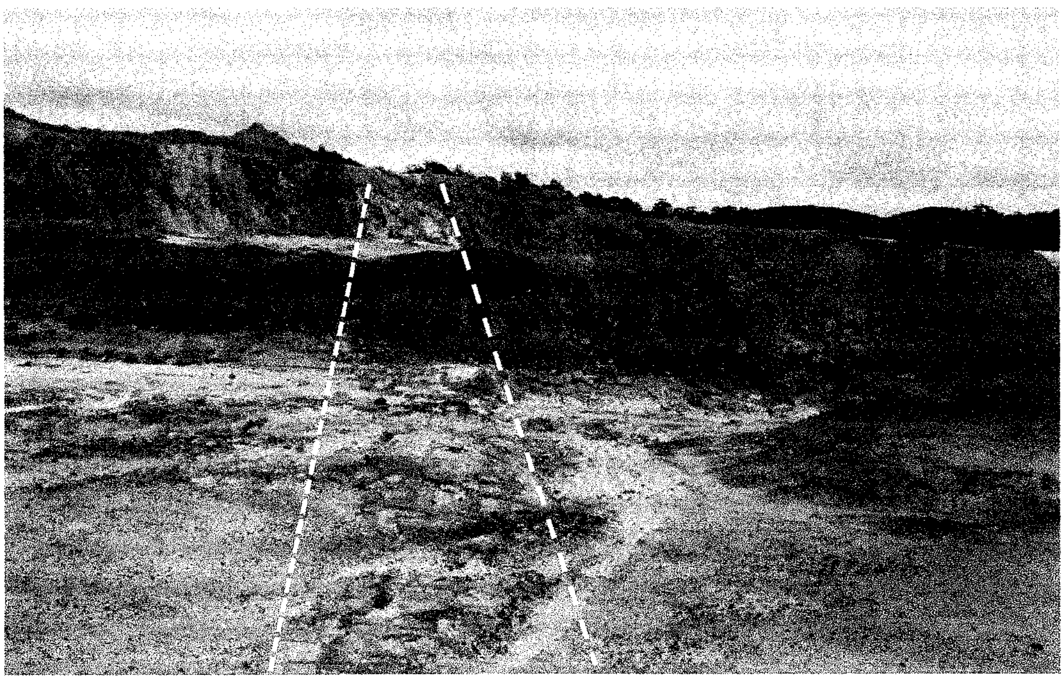


Figure 4.5: Shows Sand bar, light brown and flat-top bed. Note the thickening upward 2 to 4 m.

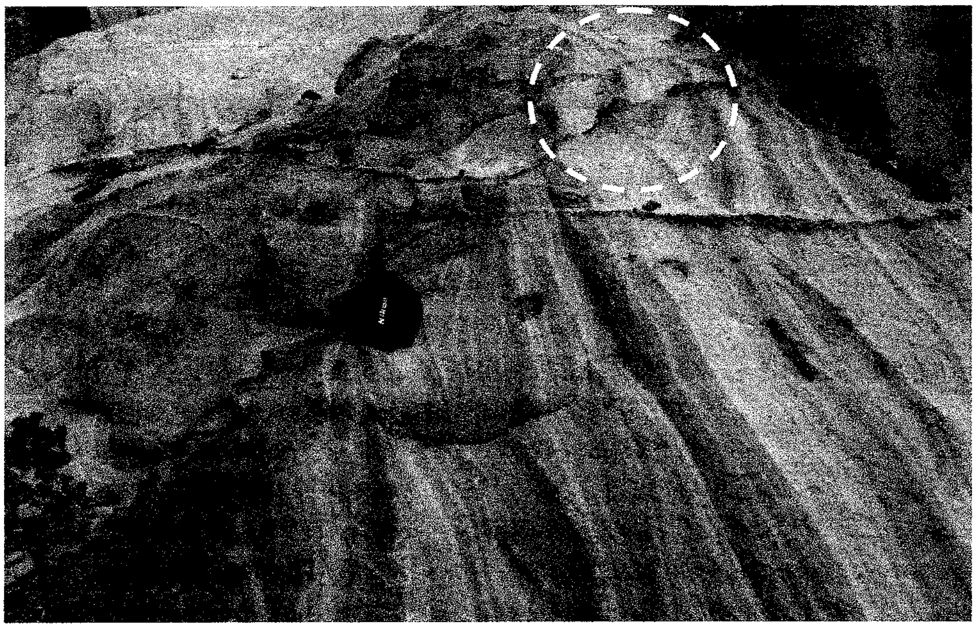


Figure 4.6: Sandstones beds commonly exhibit evidence of chemical weathering caused by iron oxide staining as indicated by Liesegang rings.

Figure 4.7: Fractures infilled with iron oxides or coatings on fracture surfaces in the sandstone beds are observed all over the outcrops, indicating a groundwater or surface flow along joints.

2. Mudstone beds

Mudstone can be found as an individual bed, but mostly interbedded with sandstone and siltstone beds. In the easternmost section of the outcrop, mudstone is found as a thick bed. This mudstone bed measures up to 46m in thickness and it is heavily mottled (Figure 4.8). This mudstone lacks primary sedimentary structures. However, the contacts between the mudstone and sandstone are sharp and are occasionally distinct with typical structures such as load casts on the lower bed surfaces which clearly indicates a younging direction of the beds towards the east (Figure 4.9).

The mudstones are gray to light gray in colour. However, mudstones and clays often show a mottling of colours, as most of the mudstone beds have undergone weathering, they show various colours of red, brown, pink and purple (Figure 4.10). From field observations at rock outcrops, mudstones could easily turn to clay by hydration and weathering.

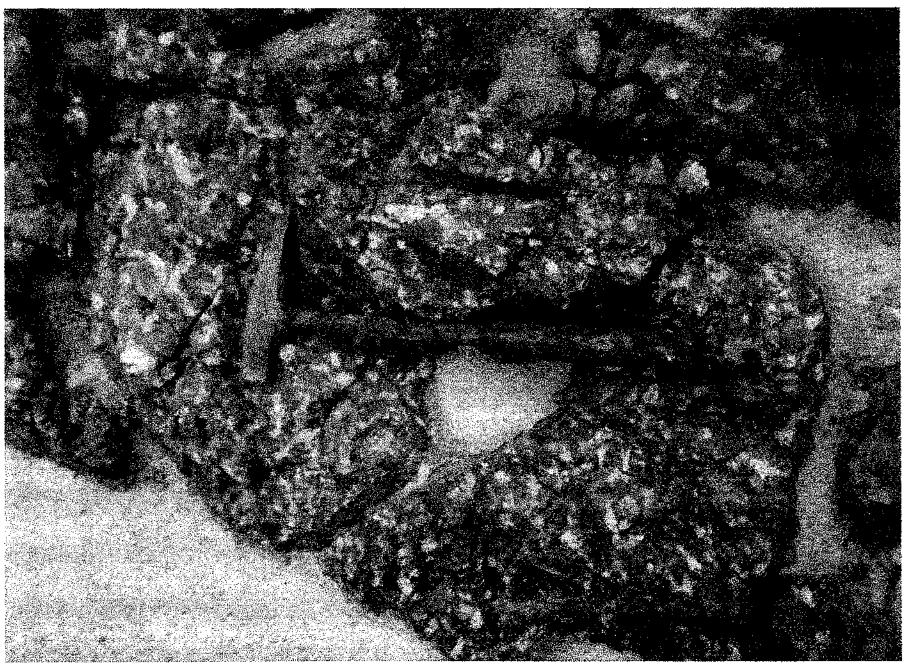


Figure 4.8: Mudstone shows a mottled texture.

Figure 4.9: Fine-grained sandstone beds are sharp-based, occasionally exhibit load casts, extending into the underlying mudstone.

Figure 4.10: Mudstone beds show a wide range of colours (red, brown, pink and purple) depending largely on the amount and the nature of iron rich and due to the effects of weathering some mudstones changed to clay.

3. **Siltstone beds**

Siltstone is rarely found as an individual bed as it is mostly interbedded with sandstone and mudstone. This siltstone is typically less than 10cm thick, but can be up to 50cm thick. The siltstone shows similar internal features as the sandstone beds. Siltstone is very fine-grained and quartz-rich, giving the bed a striped appearance.

4. **Thinly interbedded sandstones, siltstones and mudstones.**

There is a thick unit with a maximum thickness of 30m in the central portion of the outcrop [A]. It consists of alternating beds of sandstone, siltstone and mudstone. The beds range in thickness from 1 to 20cm. Sandstone beds display sharp basal contacts ~~with randomly distributed load structures. There are internally slump-folded beds.~~ Despite the thickness of individual beds, they can be traced vertically over hundreds of meters, where exposure allows. These alternating beds are interpreted generally as the deposits of turbidity currents (Figure 4.11).

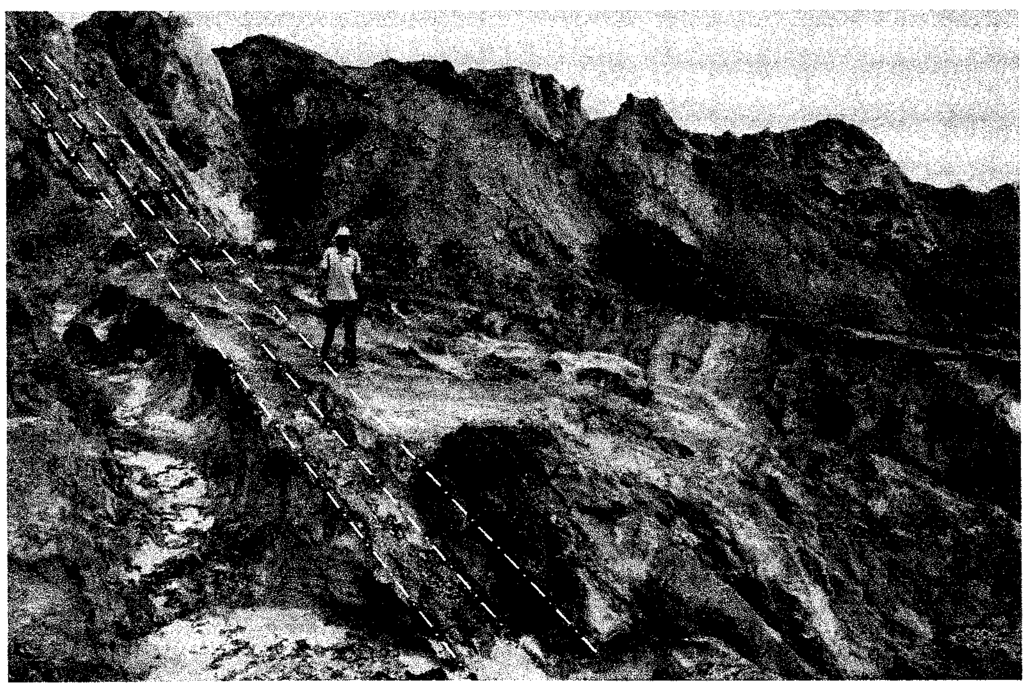


Figure 4.11: Thinly interbedded, alternating sandstone, siltstone and mudstone beds.

Despite the poor quality and generally weathered nature of these outcrops, sedimentary structures can be found locally. **Sedimentary structures** which have been recognized in these clastic beds include load casts, graded beddings, laminations, burrow tracks and small-scale slumps (Figures 4.12 & 4.13 A,B). The facts that these beds are sub-vertical imply that the area had undergone tectonic processes which had tilted the beds.

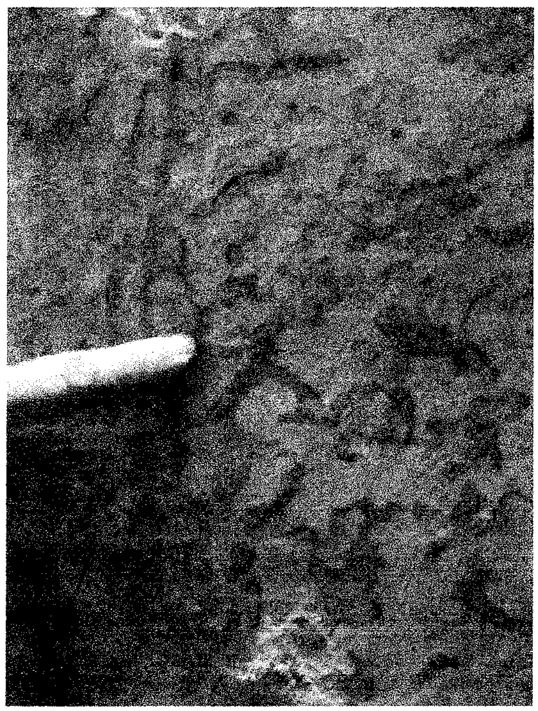


Figure 4.12: Burrow tracks in sandstone bed from the Outcrop [A] Seri Iskandar, the digenetic coloration in purple highlights the burrow tracks. The burrow tubes are approximately 5mm in diameter and are regularly spaced within this 1.5m thick sandstone bed.

Figure 4.13: A and B. Small-scale slumping structure in clastic rocks exposed on outcrop [A] Seri Iskandar, the abundance of slump structures suggests that these units were have formed as a result of gravity induced deposition in a lower slope.

4.1.2 Outcrop [B]

Outcrop [B] is located approximately 1.5km west of the previous outcrop. It is bounded by Coordinates 4°22'36" and 4°22'39"N, and 100°56'51" and 100°56'47"E. These clastic beds also appear as vertical beds. The beds generally, strike 325° and show high dip angles, varying within the range of (45 to 80°) toward the East.

They consist of alternating beds of sandstone, mudstone, and siltstone. The total thickness of the beds measured 150m. From field observation this outcrop comprises rock units which show similar structural styles and lithology as the previous outcrop and most likely, it represents a lateral extension and continuity.

The lithology is generally poorly exposed. Mudstone beds occupy the major part of this outcrop and occur mostly as thick and massive beds. The beds measure up to 40 meters in thickness and are commonly interbedded with siltstone.

This outcrop is highly weathered (Figures 4.14 A,B) and the surfaces of the beds are covered with gravels and laterite soil which are products of chemical weathering that have acted on this outcrop through time. Thus, the thickness removed by erosion is unknown. In general the clastic rocks exposed in Seri Iskandar are of poor quality; therefore, it is difficult to produce a very detailed sedimentary logs and accurate bed thicknesses, for three reasons:

1) The intensive surface weathering and erosion.
2) The absence of distinctive (marker) beds that can be used as boundaries or can be traced for any appreciable distance over area.
3) The folding of the strata in this region.

Therefore, the estimate of the thickness is at best approximate.

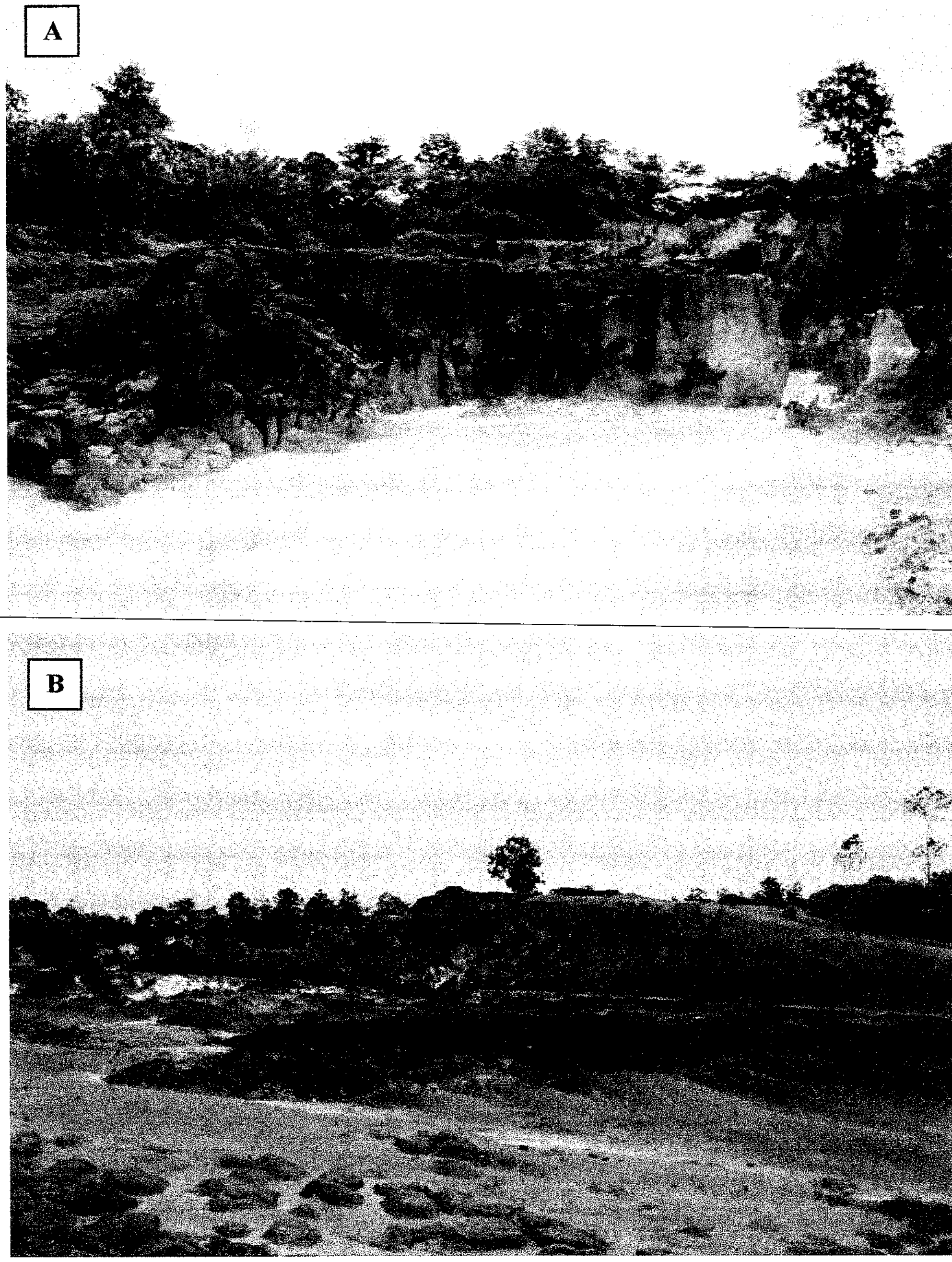


Figure 4.14: A and B Photograph shows an overview of the stratigraphy at outcrop [B] in Seri Iskandar.

4.1.3 Outcrop [D]

Outcrop [D] is an exposed road cut along a new road lead to Parit, cut through a sandstone hill and is bounded by Coordinates 4°22'54" and 4°22'58"N, and 100°56'34" and 100°56'35"E. The cutting on the western flank of the road shows a bedding strike of 330° (~NNW-SSE) with dip angles varying within the range of (~50 to 60°) towards the west. These highly weathered clastic beds predominately consist of alternating beds of sandstone, mudstone and siltstone. The cutting on the eastern flank of the road is highly fractured and has undergone intense faulting (Figures 4.15 & 4.16 & 4.17). Iron concretions are also found in this outcrop.

Figure 4.15: Panoramic view of outcrop [D] (the eastern flank) in Seri Iskandar.

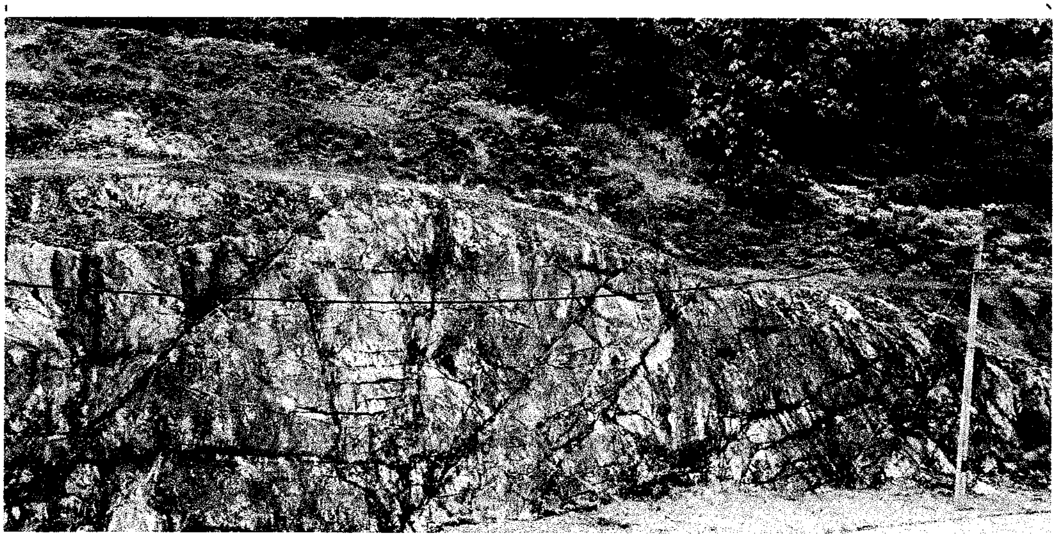


Figure 4.16: Rocks appear structurally complex tilted and generally associated with numerous faults and joints, at outcrop [D] (the eastern flank).

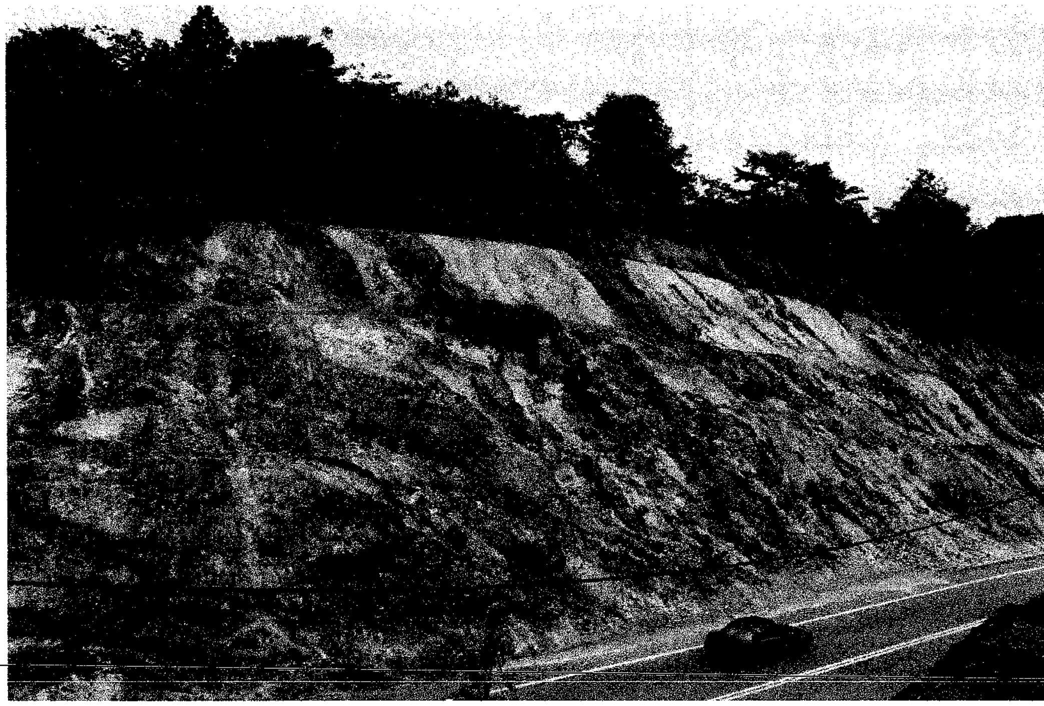


Figure 4.17: Photograph shows an overview of the stratigraphy at outcrop [D] (The cutting on the western flank) in Seri Iskandar.

4.1.4 Outcrop [E]

Outcrop [E] is located near Sekolah Menengah Kebangsaan Seri Iskandar, with Coordinates 4°21'53.20" to 4°21'50"N, and 100°57'8" to 100°57'7.28"E (Figures 4.18 & 4.19). Generally, like the previous outcrops, Outcrop [E] has the same lithology; it also consists of alternating beds of sandstone, mudstone, and siltstone. The bedding characteristics are quite similar to those the previous outcrops [A and B].

Figure 4.18: Panoramic view of the outcrop [E] near Sekolah Menengah Kebangsaan displaying similar bedding characteristics and pattern to outcrops [A].

Figure 4.19: Photograph shows an overview of the stratigraphy at Seri Iskandar outcrop [E].

4.1.5 Paleontology

According to Ingham and Bradford (1960) plant remains were found in shales by Savage (near the old 15 ½ mile post) along the Siputeh and Parit road (approximately 16 km to the northwest from Seri Iskandar). Therefore, Seri Iskandar deposits have been investigated for fossils using the standard field methods for obtaining fossils by Coe et al. (2010) pairs with thin section observations. Unfortunately no fossils have been found within these deposits.

4.1.6 Weathering

Paying attention to the characteristic weathering that developed on these outcrops (superficial weathering) is very important to the study. Moreover, the fact that these sandstones are highly weathered yield some clues about their reservoir quality (potentially).

According to Ingham and Bradford (1960), the rocks that crop out in the southwest part of Tronoh and extend for some distance to expose along the Siputeh and Parit (the adjacent to Seri Iskandar) are highly weathered. Commonly, sandy loams over sandstone and ferruginous gravel can be encountered where shale predominates. It was very difficult to penetrate even by drilling (particularly beds of nearly loose fine sand). Limonitic and iron concretions or nodules also occur at this locality.

As observed during the fieldwork in Seri Iskandar, these clastic outcrops are highly weathered and weathering characteristics of these outcrops are consistent with the observations of Ingham and Bradford (1960). Moreover, they are exposed to chemical weathering. The main chemical weathering features found include concretions and nodules, liesegang rings, dendrites and colour mottling. The effects of chemical weathering on exposed rock in some cases produce pseudo-structures that mimic other primary and secondary features (Stow, 2005).

- **Concretion**

A concretion is a compact aggregate of mineral matter found in a host rock which usually has a different composition. Most concretions are roughly spherical, but they can also be cylindrical, disc-shaped or irregular, perhaps even resembling a fossilised animal part, such as a limb bone or skull. Concretions form by chemical processes operating within sediment during burial and diagenesis; thus, they are regarded to be secondary in origin (Boggs, 2009). The most common of these 'pseudofossils' are concretions, nodules and dendrites.

Iron oxide concretions or nodules in Seri Iskandar show brownish to red colour and occur in various shapes with different degree of sphericity (Figure 4.20 A, B). These rounded concretions when broken open, reveal fine-grained textures. These concretions which average 2cm in size occur randomly throughout the succession (Figure .21).

The concretions are presumably digenetic in origin and formed in situ. Concretions are valuable records of diagenetic, post-depositional changes in sedimentary units because they preserve evidence of groundwater flow and water-rock interactions resulting in mineral dissolution and precipitation (Chan et al., 2007).

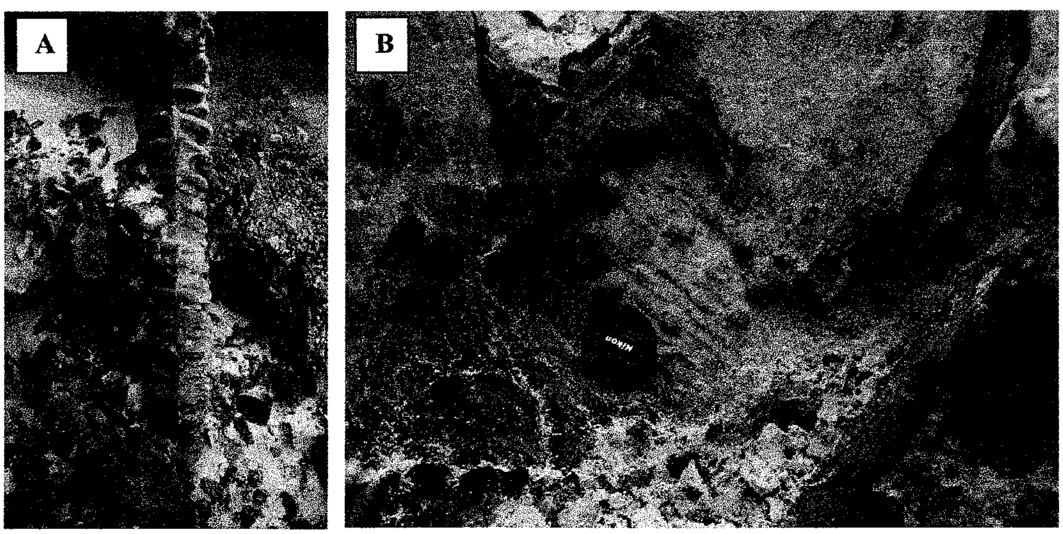


Figure 4.20: A & B Beds of this unit contain abundant digenetic features and several types of spherical concretions and nodules, sandstones of Seri Iskandar outcrop [A].

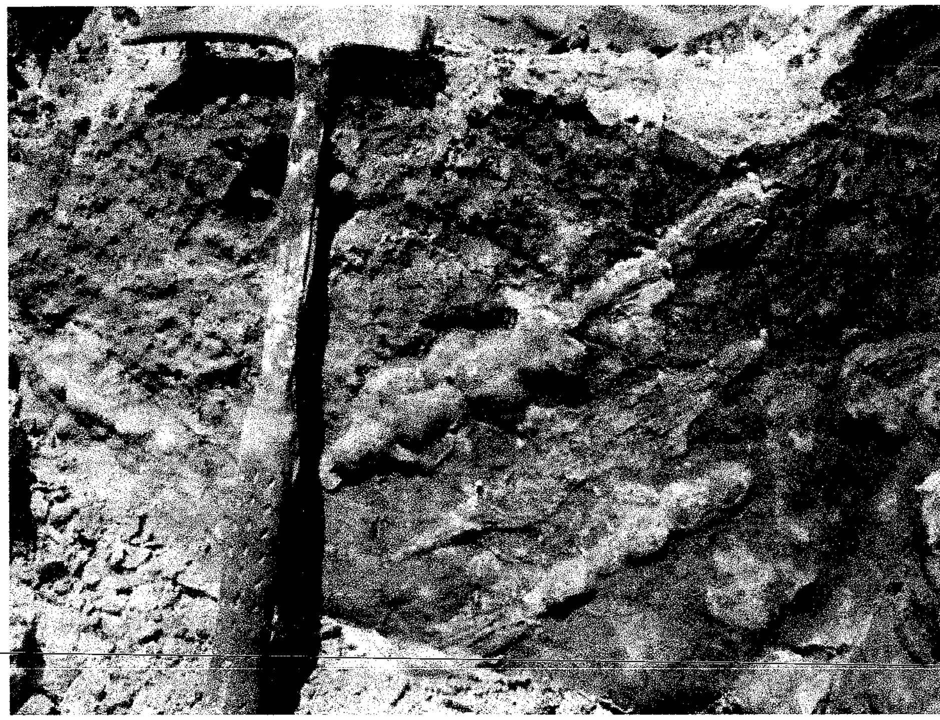


Figure 4.21: Photograph shows rounded concretions when broken open, they reveal fine-grained textures, Outcrop [A].

A study was conducted by Ismail et al. (2012) using the geophysical technique Ground Penetrating Radar (GPR), to estimate the depth to water table and to map the stratigraphy of Seri Iskandar. The results of this study suggest that, the water table in Seri Iskandar area varies between a 15-20m.

Deposition of alluvium made up of medium to coarse grain marine sand mixed with clayey sand is identified at depth (<10m) resulting in the thickness of this layer approximately 7m. Clear reflection of some dipping features and non-uniform layer of sediment deposition are observed throughout this layer.

- **Liesegang rings**

Liesegang rings (banding), sometimes referred to as colour banding, is a type of rhythmic layering resulting from the precipitation of iron oxide in fluid-saturated sediments to form thin, closely spaced, commonly curved layers. Layers having various shades of red, yellow or brown alternate with white or cream layers. It is commonly developed away from joints and other zones of fluid migration. Liesegang rings may resemble primary bedding or lamination, but can almost always be distinguished by careful study (e.g., colour banding may cut across primary stratification) (Boggs, 2009).

- **Dendrites**

Dendrites are delicately branched deposits of black minerals (typically manganese oxides) that have been precipitated from water seeping through fractures in fine-grained rocks (weathering product). While their close resemblance to fossilised fern fronds can have great aesthetic appeal, dendrites are much less regular than plant fossils and lack features such as vein structures. Dendrites were observed in the Seri Iskandar outcrops (Pierson et al., 2009).

- **Colour mottling**

Commonly, mudstone is mottled with greenish-gray mottles with yellowish and red, brown patches. These indicate iron oxide coatings on the clastic grains. The red colour indicates fully oxidized iron whereas the green colour indicates iron coatings with partially reduced iron. As observed during the fieldwork in the Seri Iskandar outcrops, laterites and iron-oxide stains are also common in this area.

4.2 Geological Structures

The geology of Kinta Valley and the surrounding area is complex and varied and our knowledge of the detailed structural geology is very incomplete. Few attempts have been made to investigate the major structural features in Kinta Valley and the surrounding areas e.g., Ingham and Bradford (1960), Gobbett (1971) and Wong (1991). However, so far no attempt has been made to describe the structure in the Seri Iskandar area. Therefore, detailed and general structural observations were made on four outcrops in Seri Iskandar area particularly, at the road cut site outcrop [D]. The primary aim of this investigation is to observe the structural characteristics and collect some structural measurements of orientations of bedding, faults, and fractures (strike and dip measurements).

- **Structural Features Observed in the Outcrops**

These outcrops are characterized by the presence of large and small scale structures. The most common structural features observed in these outcrops include well-developed faults, joints, veins, infilled joints and fractures striking ~NNW-SSE and dip (45 to 60°) to west. The overall structural style and character of these outcrops suggest that these rocks are structurally complex.

It also offers some ideas about the deformational history considering that these structures show a wide variety of chaotic structure deformation and faults and relatively tight open folds (Figure 4.22).

The existence of this complex structural style suggests that these clastic rocks have undergone a moderately to strongly deformation, (probably as a result of compressional phase or tectonic activity in the late Triassic at the time when Sibumasu collided with East Malaya and Indochina blocks). However, they were hardly affected by contact metamorphism. The fact that these beds are no longer horizontal (highly folded) indicates that they formed presumably before the tectonic event (Triassic time).

Our observation is in agreement with a previous studies by Foo (1990) and Wong (1991) in which they found that the Kati beds (Formation) appear in general to be more severely folded than the Semanggol Formation suggesting older age (Foo, 1990). Moreover, it has undergone a moderately to strongly deformation during the Triassic resulting in the formation of relatively open flexural folds of wavelengths varying between 2 and 8km (Wong, 1991).

- **Faults**

The majority of the outcrops in Seri Iskandar expose a series of local faults, which can be followed uninterruptedly over some distance (vertically and horizontally) especially at Outcrop [D] (Figure 4.23). Most of the faults are strike N to NNW and dip steeply to near-vertically, to the S to SSW. The absence of distinctive (marker) beds made it difficult to assess the amount of displacement in these faults.

However, based on satellite images (Figure 4.24) and the structural map of Peninsular Malaysia (2008) which shows the major faults across the Peninsula (Figures 4.25), no major (regional) faults have been recognized in the Seri Iskandar area.

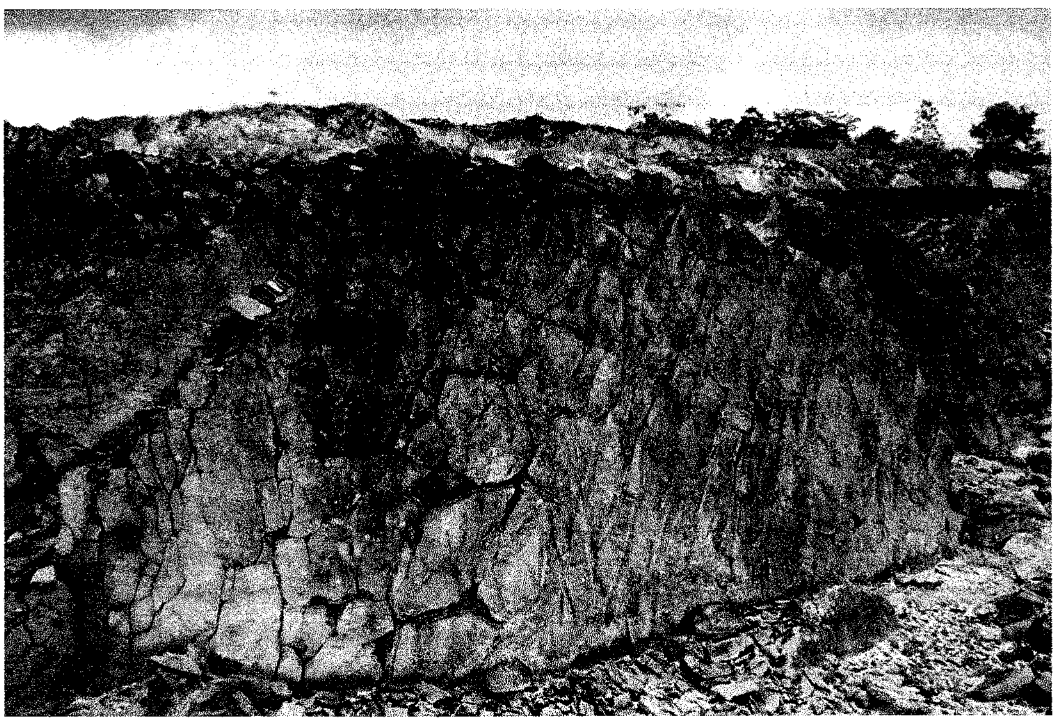


Figure 4.22: Outcrop [A] exhibiting chaotic structures deformation, this unit is laterally continuous over several meters.

Fracture data analysis revealed that three distinct deformation events (faulting episodes) can be recognized in the outcrops:

1) Sets of normal faults
2) Sets of reverse/thrust fault
3) Sets of conjugate fracturing

Detailed descriptions of the fracture data analysis are included in the Appendix.

The presence of various (different) fractures types (e.g., conjugate fracturing) indicates that these clastic rocks have been subjected to considerable stress (compressional and extensional stresses) and probably formed as a result of deep burial or strong tectonic forces /deformation.

Figure 4.23: Outcrop [D] shows three sets of local faults (white, red and yellow colours) can be followed uninterruptedly over some distance (vertically and horizontally).

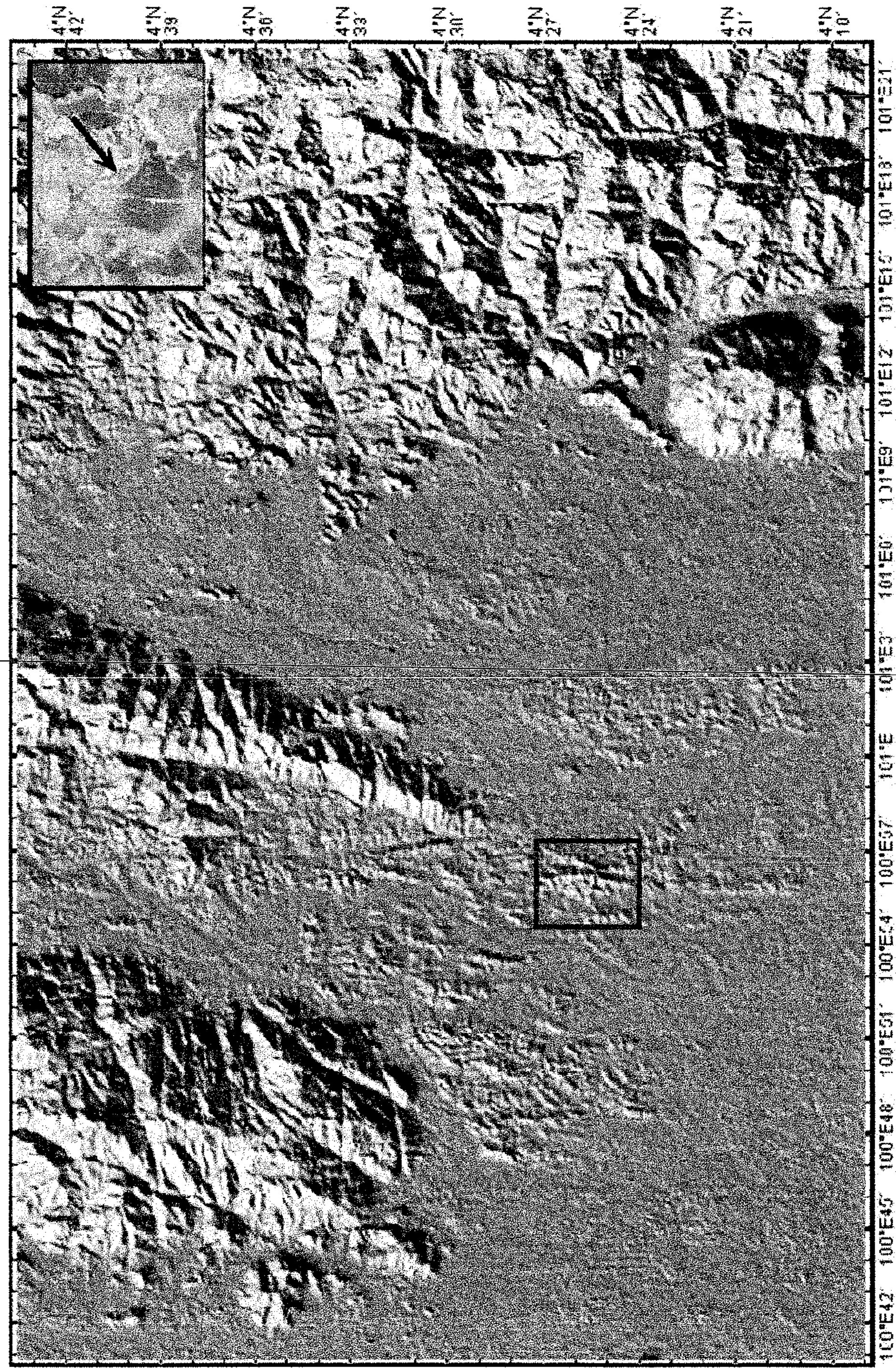


Figure 4.24: Digital elevation model (DEM) map illustrates the basic structural features (the major faults) occur in Kinta Valley and the surrounding area; the study area shown by red box.

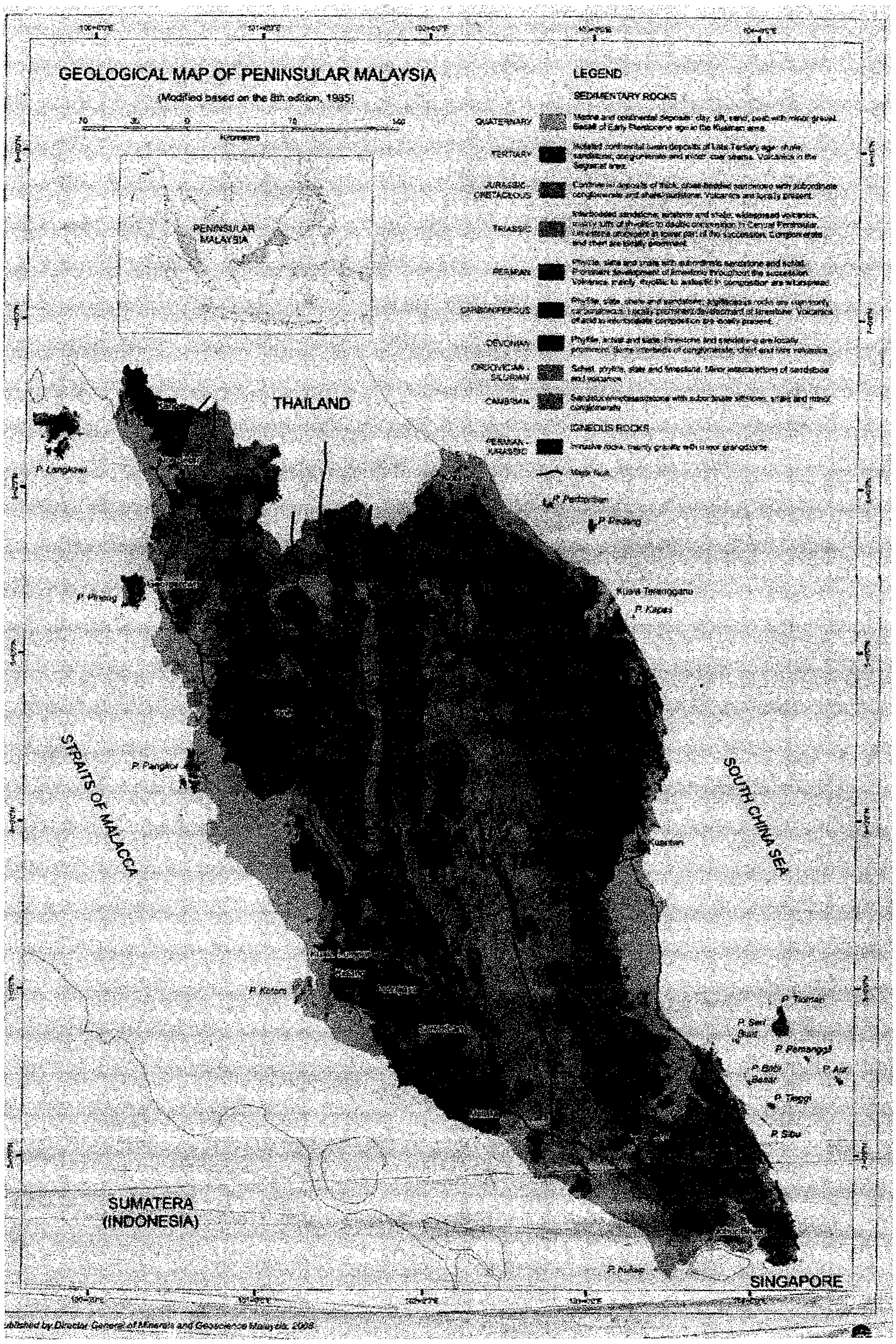


Figure 4.25: Simplified structural geologic map of Peninsular Malaysia. Thick lines indicate major faults. The position of the investigated area at Seri Iskandar is marked with red box, from Director General of Department of Minerals and Geoscience Malaysia (JMG), 2008.

- **Conjugate fractures**

Conjugate sets of shear fractures occur in this area symmetrically disposed around the strike fractures, oriented with a small angle less than 60° with respect to vertical (Figure 4.26 A,B). This conjugate fracturing formed as a result of multiple stress system in different directions which existed during the deformation. Similar conjugate sets were observed on the limestone at the Kinta Valley; they strike N to S, and have moderate dipping (8 to 45°) (Chee Meng, pers. comm.).

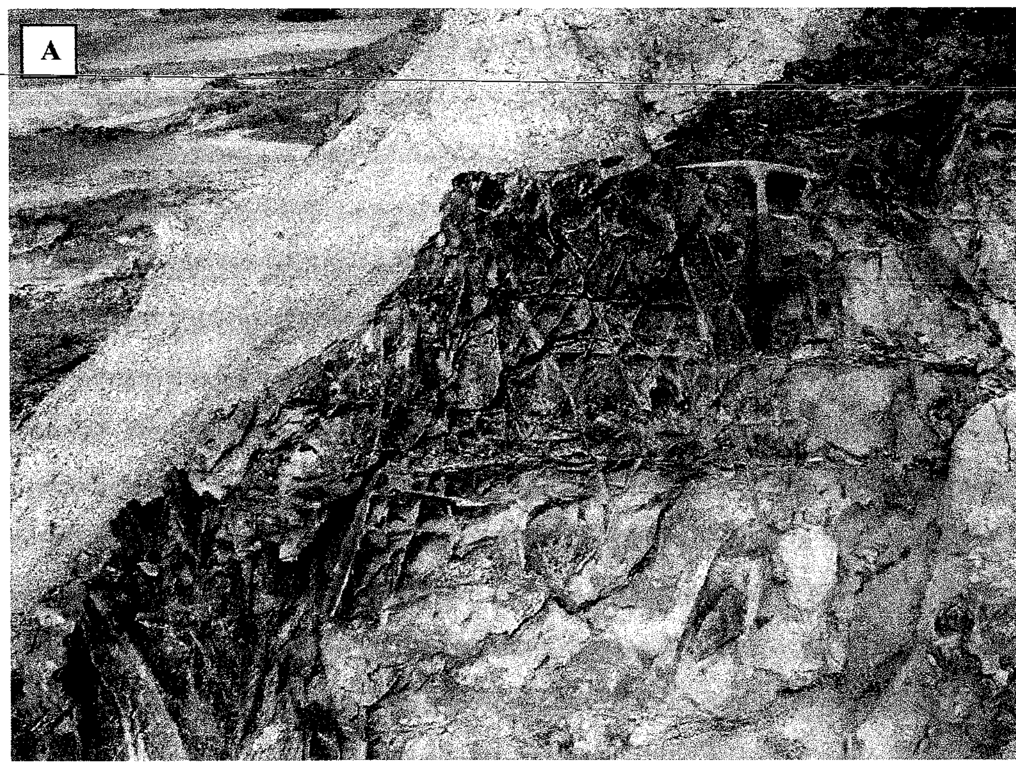


Figure 4.26: A &B Conjugate network of shear fractures in sandstone at outcrop [A]. The spacing of the fractures typically varies strongly over distance. Note the iron oxide filled fractures.

- **Folds**

A number of local and relatively open anticline and syncline folds have been observed in some localities at Seri Iskandar. This observation is consistent with observations of Foo (1990) and Wong (1991) in their area of study of Kati Formation. Furthermore, these types of folds are also found in the limestones of the Kinta Valley (Ingham & Bradford, 1960; Lee, 2009; Rajah, 1979; Gobbett, 1971).

In this poorly exposed area where tectonic events have taken place, distinguishing slump structures (gravitational failure) from tectonic structures can represent a real challenge. However, many folds in limestone in the Kinta Valley have been interpreted by Pierson et al. (2009, 2011) as syn-sedmentary structures or slump. Moreover, they suggest that the slump folds formed during deposition rather than as the result of the tectonic deformation (Figure 4.27). They also suggest that this syn-sedmentary folding resulting for plastic/ductile deformation of soft but cohesive fine sediment layer due to gravity-induced lateral downward movement, is usually on a slope.

Figure 4.27: Part of a complex slump exposed in an abandoned black limestone quarry at Sungai Siput, Perak. The layers involved in the slump include chert (in light grey), micritic limestone (medium grey) and carbonaceous shale (dark grey), from Pierson et al. (2009).

- **Veins and joints**

Veins and joints are common features in all Seri Iskandar outcrops especially at Outcrop [D] because it is more resistant to weathering (erosion) than other outcrops. Some fractures and joints were occasionally filled by white calcite or iron oxide infilling or coatings on fracture surfaces, indicating a groundwater or surface flow along joints (Figure 4.28). Joints are also common features in the limestone and granite of Kinta Valley (Ingham & Bradford, 1960; Gobbett, 1971; Foo, 1990).

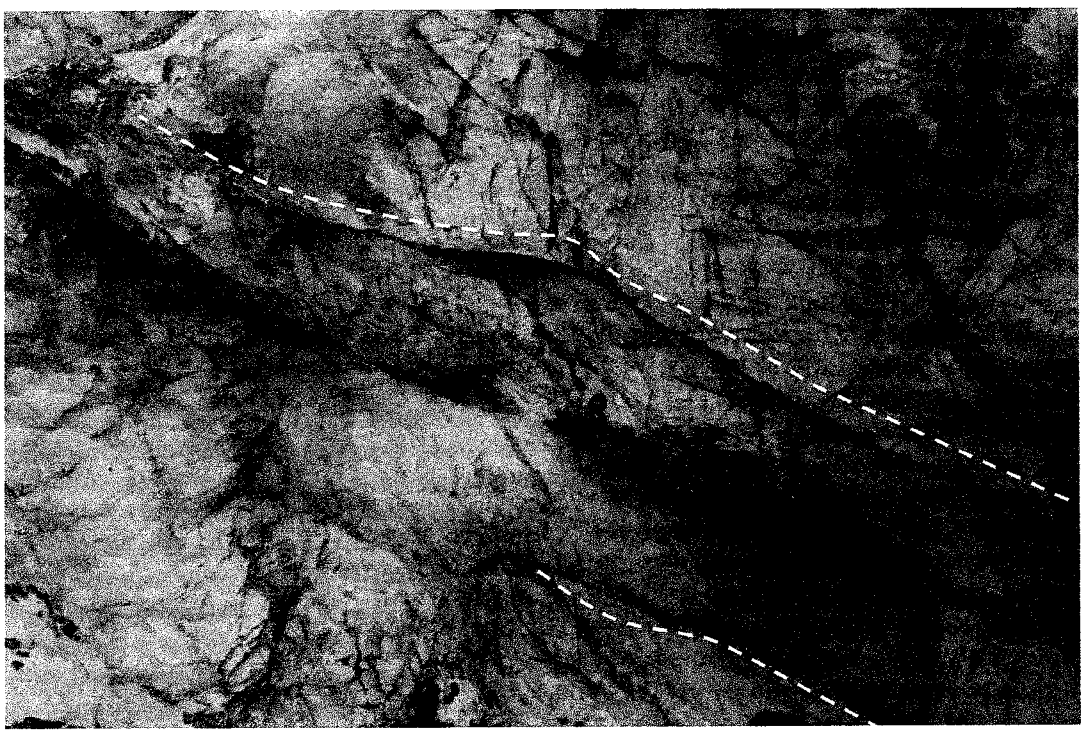


Figure 4.28: Sandstone bed showing a central zone with abundant veins and joints. Note the iron oxide infilling or coatings on veins at Outcrop [A].

4.3 Laboratory Work

The petrography of sandstones in Seri Iskandar areas has not been studied previously. The main objective of this section is to deal with the general petrology of Seri Iskandar sandstone. Furthermore, understanding the petrology of these sandstones will allow for better assessment of their reservoir potential. To achieve this purpose, samples from the field were made into thin sections and also used for laboratory tests and analysis. This included petrophysical studies (Porosity and Permeability measurement) and petrographic studies, which included a description of the rock type mineralogical composition, texture, matrix, cement, porosity, permeability and main diagenetic processes affected the sandstone.

4.3.1 Thin section study (Sandstone petrography)

Thirty representative samples from outcrops (A and D) were selected and sent to the Minerals and Geoscience Department Malaysia (JMG) to be made into thin sections. A total of 25 petrographic thin sections were prepared, so that at least 10 thin sections were available from each of the outcrop (A and D). The sandstones from outcrops (B and C) were too friable for thin sectioning.

Thin sections of all samples were analyzed using a petrographic microscope (BX51,Olympus) equipped with a CCD Camera (DP72,Olympus) in the South-East Asia Carbonate Research Laboratory (SEACARL).

- **Constituent minerals**

The thin section study revealed that the sandstones of Seri Iskandar are dominantly composed of cemented quartz with subordinate feldspar and minor amounts of black grains of heavy minerals. This sandstone shows variation in sandstone classification and grain size.

- **Texture**

The Thin sections of the Seri Iskandar sandstone were prepared from fine to coarse grained samples. Nearly all samples consist of moderate to well sorted grains. The grains are mostly sub-angular to sub-rounded in shape. In general, coarser grains tend to be more rounded, though in a few samples well rounded grains occur in almost all size grades, and in a few others, coarse angular grains coexist with finer rounded grains (Figure 4.29).

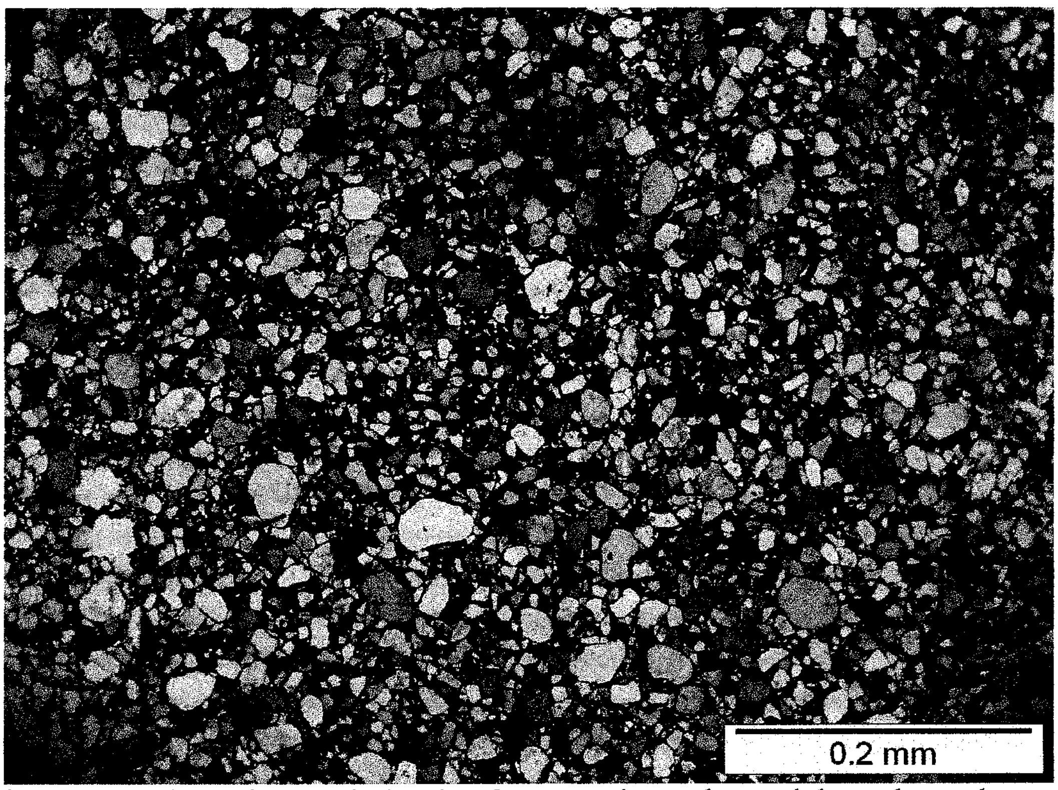


Figure 4.29: Photomicrograph showing Quartzarenite sandstone, it has sub-angular to sub-rounded quartz grains and is poorly sorted. Note the presence of iron oxide cement (surrounding the grains). Outcrop D-9.

Sandstone of Seri Iskandar consist of a high proportion of quartz grains indicate its mineralogical maturity. The nature of sorting, roundness and high clay content suggests that the sandstones in the studied area are compositionally and texturally mature.

Characters of framework grains

- **Quartz**

The quartz grains are the most dominant framework grains in this sandstone, and they form more than to 95% of the total minerals in most samples. The quartz grains are typically white, gray and mainly fine to medium and occasionally coarse. The grains are mostly sub-angular to sub-rounded in shape, though few are sub-rounded to rounded. The grains are moderately to well sorted. Generally, the grains show both straight and sutured contacts at most grain boundaries (Figure 4.30).

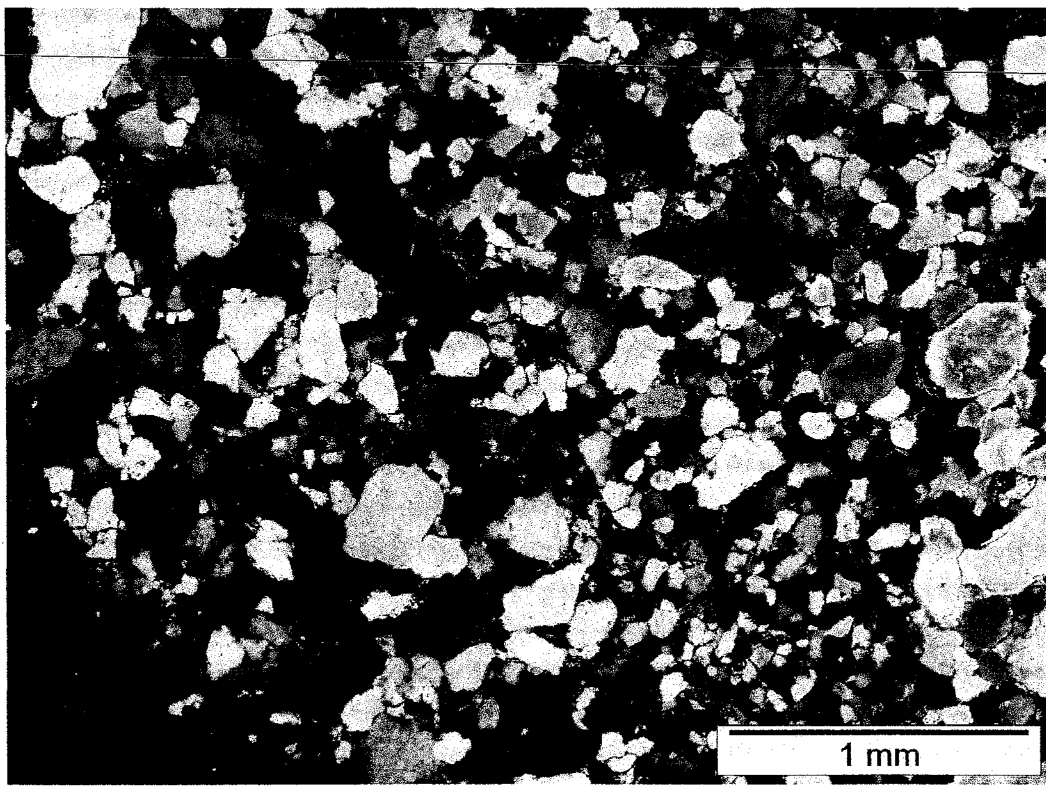


Figure 4.30: Photomicrograph showing Quartzarenite sandstone, which consist of sub-angular to sub-rounded grains of quartz, cemented and attained a texture of highly interlocked grains, with point, straight and concavo-convex contact (boundary) between the grains. Outcrop D-2. Notice, this section is thick and the quartz shows high interference colours.

Some quartz grains are highly deformed and show multiple sets of fractures or cleavage fractures (grain-scale fracturing) (Figure 4.31). Thin section examinations revealed that most of the quartz grains are monocrystalline, although undulose extinction of quartz is also noted. The polycrystalline quartz grains are absent because they are less stable and disaggregate into more stable single grains (Blatt et al., 1980).

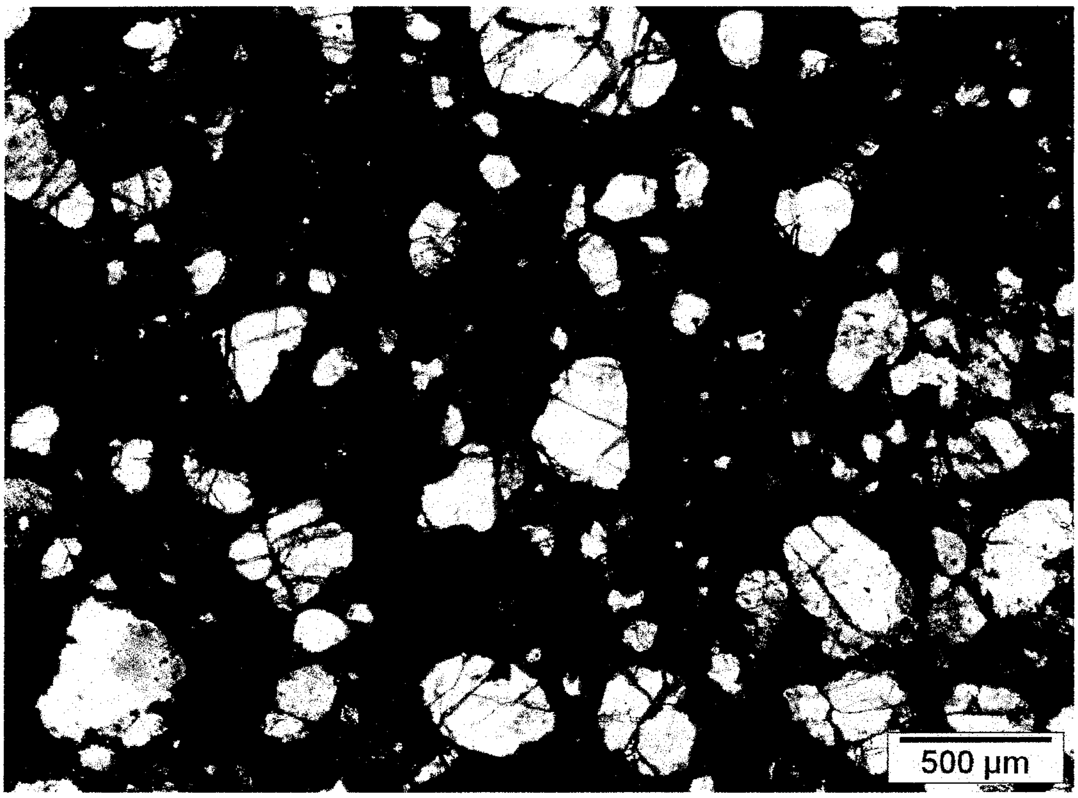


Figure 4.31: Photomicrograph showing deformation features in quartz grains in a matrix of iron oxide (fractured quartz grains). It strongly indicates that the sandstone has undergone intense compaction. Outcrop A-2.

* **Feldspar**

Feldspar is an important mineral group present in the sandstone in minor amount. Feldspars are rare, making up less than 5 percent of the rock (Figure 4.32). A few sericitized feldspar grains are recognized in the thin sections. Many feldspars grains have suffered dissolution. Moreover, many of the feldspar grains are strongly stained and impregnated with iron oxide.

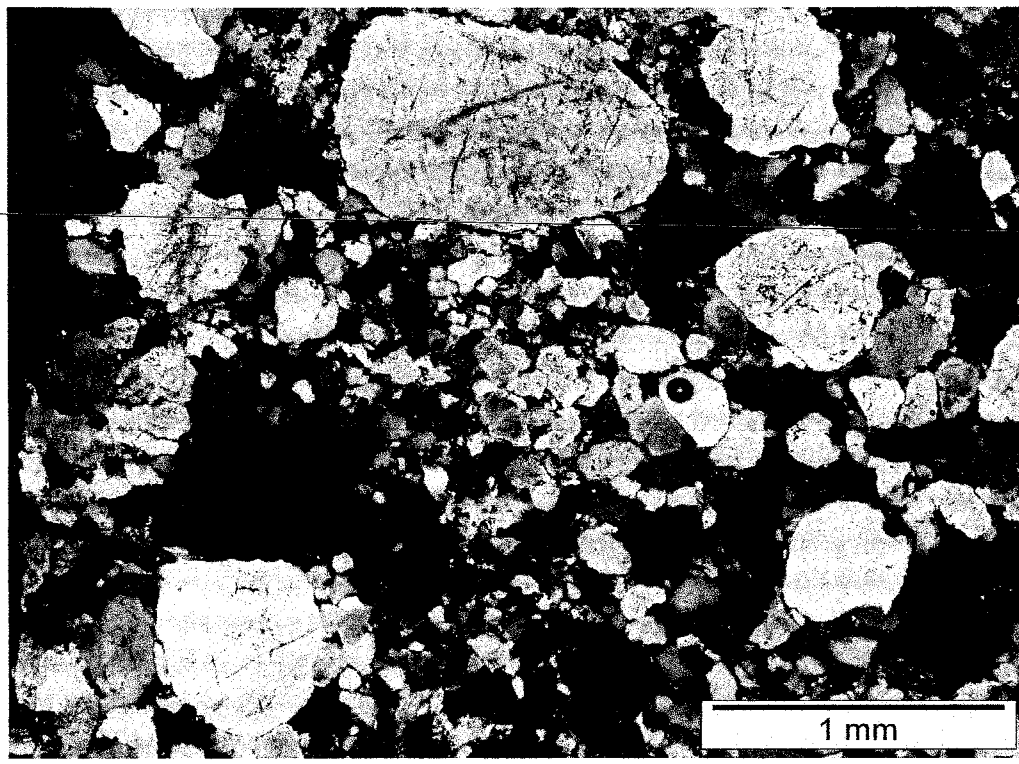


Figure 4.32: Photomicrograph showing quartzarenite, characterized by highly interlocked grains. Note the presence of angular to sub-rounded quartz and feldspar grains. Outcrop D-3.

- **Lithic Fragments (Other Minerals)**

Clay minerals are also present in many of the samples. In some samples, the clay is present as matrix. The clay is dark brown in colour and is likely to be illite. Samples containing opaque dark minerals which consist of iron oxide were found as a coating on the periphery of quartz grains or as accumulations in the pore space. Some samples showed extensive development of iron oxide along fractures. Many grains are strongly stained and impregnated with iron-oxide. Clay minerals were mostly formed as a result of alteration of feldspar grains during diagenesis. For further, future work on petrography of sandstone in Seri Iskandar a help of scanning electron microscopy and XRD are needed to identify clay minerals such as kaolinite, chlorite and illite.

Minor accessory (heavy) minerals were observed in thin sections. The heavy minerals typically form not more than 2% of the sandstone constituents and include zircon (which occurs as well-rounded grains) and Tourmaline (is mostly composed of its pink variety) are considered as secondary minerals, and they can be used for source rock interpretation. The relative amounts of these minerals depend on their abundance in the source rocks and their resistant to mechanical and chemical weathering. Among the opaques iron minerals are the most dominant.

Zircon (colourless to pale gray), tourmaline (brown, greenish brown, yellow and green), epidote (colourless, lemon yellow to the characteristic pistachio green colour), rutile (blood red colour) are the non-opaque accessories and among them tourmaline is the most dominant followed by zircon. Biotite, epidote, amphiboley (mafic contents), Zircon, Tourmaline and Rutile are also recognized from thin section examination of Kati Beds have been reported by Ingham, (1938) Foo, (1990) and Wong, (1991).

- **Cement / matrix**

The framework grains are bounded by cement and matrix. Quartz cement is the most common type of cement in the Seri Iskandar samples, whereas the iron oxides and clay matrix are less common. It is possible to find one or two or all types of cements in a rock sample.

Quartz cement in the form of quartz overgrowth is present in most of the samples, typically on detrital quartz, which can be distinguished from the original grain by a thin dust rim (dust-line); in many cases, while in other cases, the boundary between the original grain and overgrowth cement cannot be distinguished (Figure 4.33). The quartz grains of sandstone are tightly interlocked and appear as an angular grain. The extensive pressure solution processes over the grains led to the formation of sutured contact .Therefore, it makes some difficulty to recognize this type of cement (in some samples). The size of the quartz grains varies and the shape of the cement overgrowth fills adjacent pore space.

Iron oxide cement is also present in most thin sections though not as common as quartz cement, predominantly in thin sections of outcrop [D]. Iron oxide cement occurs as dark red pigments surrounding (coating) the grains and intruding the fractures. The effect of these types of cements is clear in destroying the porosity of sandstone layers.

- **Matrix**

The matrix consists largely of silt-sized quartz and microcrystalline clay minerals. The matrix also includes a small amount of chlorite and sericite. The matrix content decreases in quartzwacke and eventually almost disappears in the quartzarenite samples. Both framework grains and matrix are heavily iron-stained (coated with iron oxide). Clay matrix content and burial depth are the most effective factors controlling the formation of silica cement (Dutton et al., 1991).

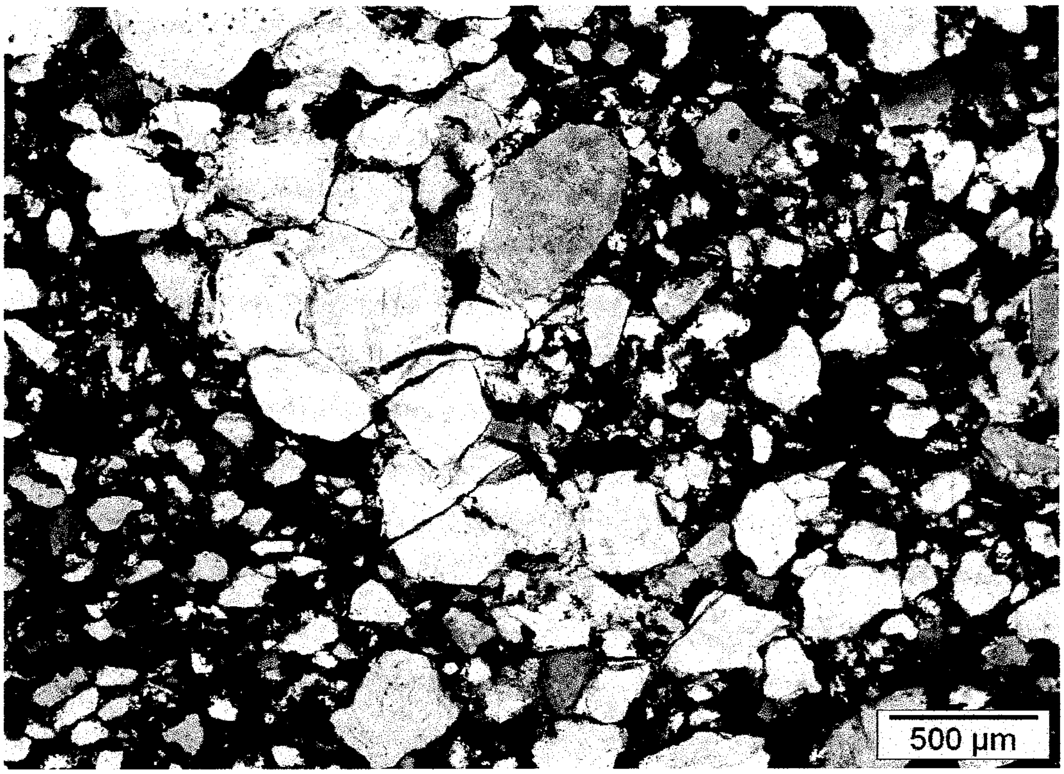


Figure 4.33: Photomicrograph showing quartzarenite with quartz overgrowth cement and sutured boundary between quartz grains. Notice the dust-line developed between the overgrowth and the quartz grains. It is also illustrates the contact boundaries between the quartz grains. Note this quartz shows higher than usual interference colours, Outcrop A-4.

- **Thin section analyses**

These sandstones were classified and identified based on their texture and mineralogical composition as observed in thin section, following classifications of and McBride (1963) and Folk (1980) into two main petrographic groups: quartzarenites and quartzwackes.

1) **Quartzarenite**

Petrographic analyses showed that the vast majority of samples are quartzarenites. The framework grains are composed almost exclusively of monocrystalline quartz (nearly 95 %) with subordinate amount of feldspars and rock fragments. Overall, this quartzarenites sandstone showed good sorting and made of sub-angular to sub-rounded grains of quartz, medium to coarse-grained, and generally devoid of matrix (Figure 4.34).

This typical quartzarenite is tightly packed and the pore spaces are entirely filled up by quartz cement often occurs as overgrowths on the original quartz grains. The sandstones consolidation seems to have been effected mainly by pressure welding as a result most of the mineral grains become tight and interlocking. These quartzarenites are texturally and compositionally mature.

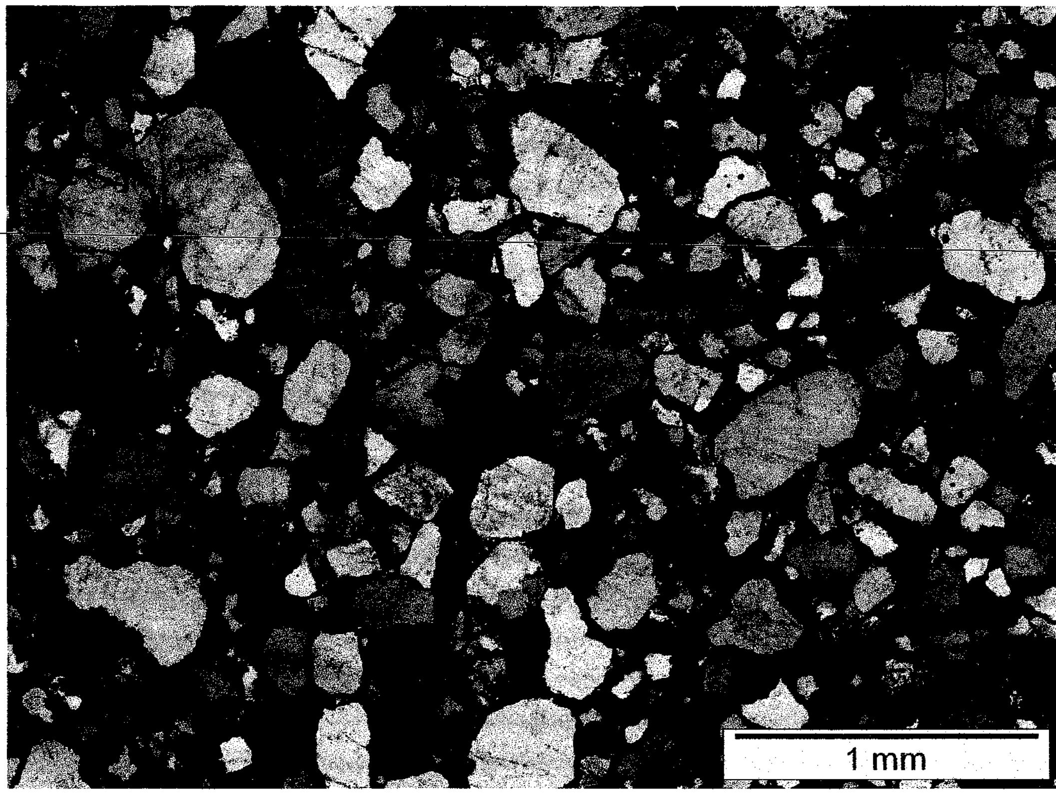


Figure 4.34: Photomicrographs showing quartzarenite well sorted, medium-grained with quartz overgrowth cement.

2) **Quartzwackes**

A few samples show decrease in quartz grains to 85% and increase in clay matrix to about 15%, of the total constituents and therefore are classified as quartzwacke. The detrital clasts are similar to those in the quartzarenite. They consist of predominantly fine quartz, chlorite, sericite, with iron oxide coating the detrital grains. They consist of less well sorted grains and are fine to medium grained. They appear to be composed of sub-angular to sub-round quartz grain (crystalline quartz). The consolidation is mainly due to the cementing effect of the matrix. In general, wackes are argillaceous, matrix rich, texturally immature, or "dirty "sandstones (Figure 4.35).

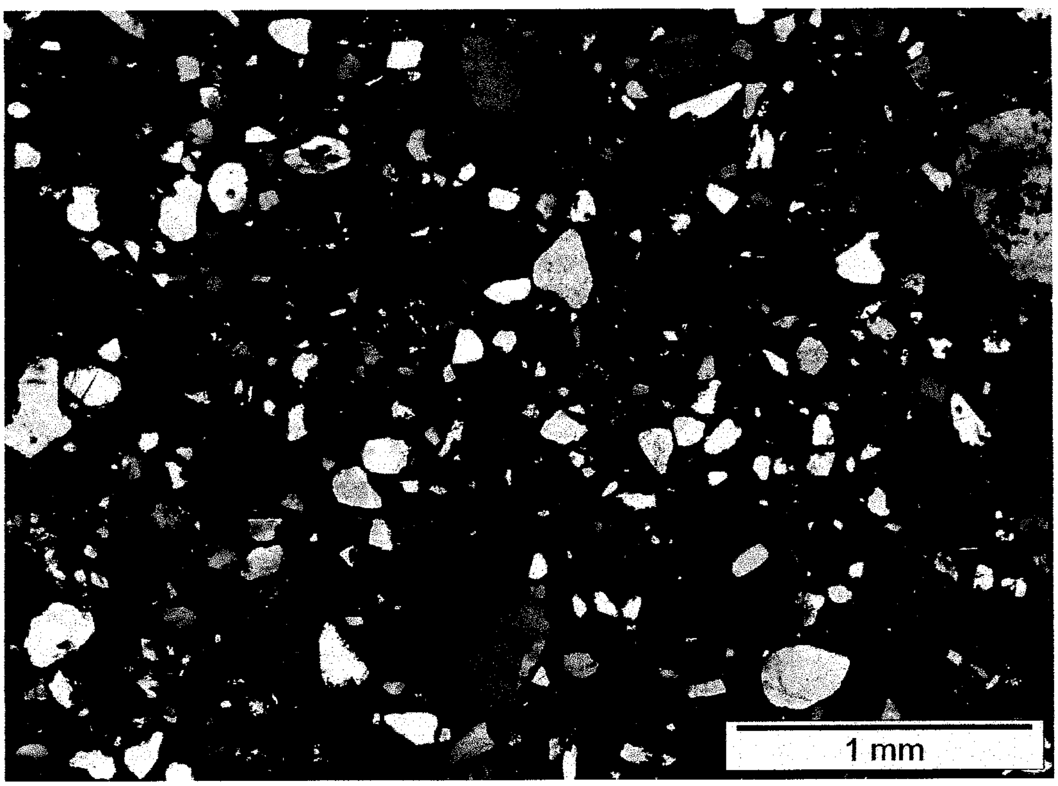


Figure 4.35: Photomicrograph showing a poorly sorted medium-grained Quartzwacke, dominance of rounded quartz and rare feldspar grains. Note the abundant iron-oxide. Outcrop A-5.

Estimation of Porosity and Permeability

Porosity and permeability data are essential to estimate the reservoir potential. Therefore, to help provide a full estimation of rock properties of sandstones in Seri Iskandar, porosity and permeability measurements on core plug samples integrated with thin section analysis were carried out using two techniques as follows:

1) Petrophysical investigation

The porosity and permeability of seven sandstone core samples were measured by the standard gas expansion method (helium injection) using the Coreval 30® instrument. These measurements have been carried out at the Center of Excellence for Enhanced Oil Recovery laboratory (EOR).

2) Petrographic investigation

Thin sections of about 25 samples representing Seri Iskandar sandstones were used to study the porosity and permeability by a petrographic microscope at the South-East Asia Carbonate Research Laboratory (SEACARL).

- **Petrophysical investigation**

As observed during the fieldwork in Seri Iskandar, the outcrops are very heavily weathered. They are very difficult to penetrate in drilling (particularly beds of nearly loose fine sand). In most outcrops, surface core plugs could not be made. However, 10 surface core plug samples were obtained from outcrops (A and D) using a portable rock core drills Pomeroy Model D026-C-BSS-1E bit, producing 1.5 to 1.0-inch plugs core. Some core plug samples were unsuitable for testing because they were too friable. Seven core plug samples were labeled and stored individually into small plastic bags. Accordingly, these samples were placed in a 105°C drying oven for 24 hours and then into evacuated desiccators for cooling them to ambient temperature to minimize contamination due to condensation from the atmosphere (Figure 4.36).

The porosity and permeability of the cores were measured using Poroperm-Coreval 30®instrument. This instrument is dedicated to measure the porosity and permeability with helium on plug-sized core samples at a fixed confining pressure of 400 psi maximum. Porosity and pore volume measurements are made using the Boyle's and Charles' law technique. The definitions of porosity and permeability and methods of laboratory measurement "routine core analysis" can be found in American Petroleum Institute (1956, 1960).

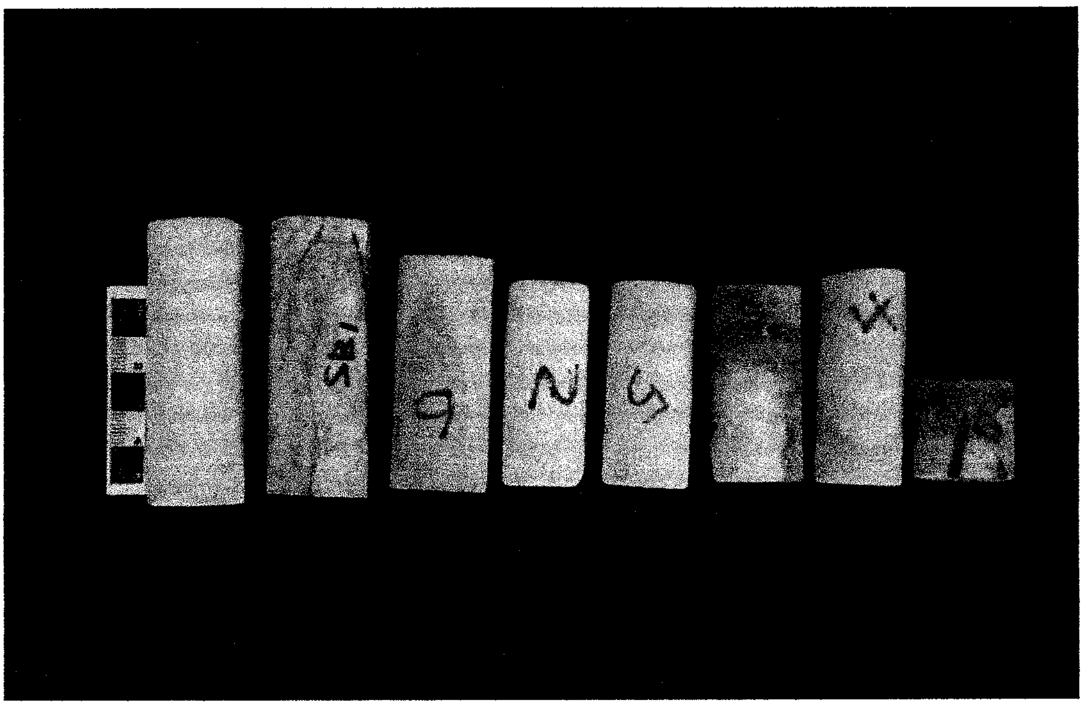


Figure 4.36: Photo of the Seri Iskandar surface core plugs (Cores SA-SB) tested in EOR laboratory.

Results from petrophysical investigation (Poro-perm)

- **Porosity**

The measurements on some sandstone core samples show high porosity (17-24%). This high porosity core samples were taken from slightly/highly weathered beds (zone) within the outcrops (weathered surface). Therefore, this high porosity is greatly enhanced by weathering processes. Nevertheless, a couple of cores show the impossibility of measuring porosity. These core samples were taken from well cemented and well compacted beds (Table 4.1). Well cemented quartz sandstone may be extremely resistant to weathering, whereas sandstone with high clay content is likely to be soft and weak and weather rapidly (Hamblin et al., 2001).

Sr.No	**Core Id.**	**Diam., (mm)**	**Length (mm)**	**Bulk Volume**	**Porosity %**
1	Core SB1	25.73	74.86	96.542	- 4 error
2	Core SA1	24.66	77.07	84.056	Error
3	Core SA2	22.82	55.80	43.875	Error
4	Core SA4	23.20	70.67	55.983	24.2
5	Core SA5	22.46	55.69	43.337	Error
6	Core SA6	25.83	63.55	67.907	17
7	Core SA7	24.48	53.37	56.158	Error

Table 4.1: Properties of cores and results of Helium Porosity.

To verify the accuracy and to ensure that this problem (negative/ no readings) was not due to technical issues, the measurements were repeated many times. This problem could be related sandstone (clay-rich) grains or diagenetic effect (the effects of compaction and fractures). This large variation of porosity measurement was achieved without any change in composition.

- **Permeability**

The permeability of the rock is ability of the rock to transmit fluid, Permeability is commonly correlated with porosity and is also related to the fabric or packing of the grains. Permeability is reduced in more compact, more tightly packed ancient sandstones (Pettijohn et al., 1987).

All core plugs which were cemented or well compacted and contain fractures produced permeability errors and is not reported here.

- **Limitations**

The results are limited mainly by the weathering. Hence, the tropical zone is characterized by the occurrence of deeply weathered profile (rocks). This implies that there is no possibility of avoiding the effect of weathering (resulting from surface water). A second limitation is the impossibility of measuring the reservoir properties (porosity) of highly fractured zones. The fractured zones in tight sandstones often present reservoir possibilities at depth but cannot be evaluated through this surface sampling methodology (Marcil, et al., 2005).

Petrographic Investigation (Porosity/Permeability analyses from thin sections)

Though the Petrophysical investigation of some sandstone samples showed the presence of high porosity, petrographic investigation of the sandstone show that the porosity is negligible to poor (<10%).Textural examination of cement-grain contacts has revealed that, the majority of the samples which are classified as quartzarenites are heavily cemented by quartz cement and matrix dominantly quartz overgrowth, iron oxide, and clay matrix. The grains mostly display sutured grain contacts. These sandstones were diagenetically affected by cementation and compaction. These two processes are responsible for porosity reduction in this sandstone.

- **Diagenesis of sandstones and reservoir quality**

Four main diagenetic processes affected the sandstone of the Seri Iskandar include compaction, cementation, fracture infill and dissolution and precipitation. The main diagenetic events were identified that occurred during burial:

- Clay coating around the grains.
- Compaction/dissolution of matrix grains,quartz and feldspars.
- Quartz overgrowth cementation in the remaining pore space.

While the main recent outcrop diagenetic events (processes) include:

- Secondary dissolution
- Fracture infill and iron oxide concretions/nodules

~~These fractures formed during late diagenesis (or attributed to the late diagenesis)~~ and they have a distinct pattern.

- **Compaction and pressure solution**

Compaction is attributed to the increase of overburden which consequently changes the rock texture and fabric as well as expulsion of pore fluids (McBride, 1987). Microscope observations of the sandstone of the Seri Iskandar showed that, the grains are mainly sub-angular to sub-rounded and tightly packed; with long and concavo-convex grain to grain contacts and some suture contacts (Figure 4.37).

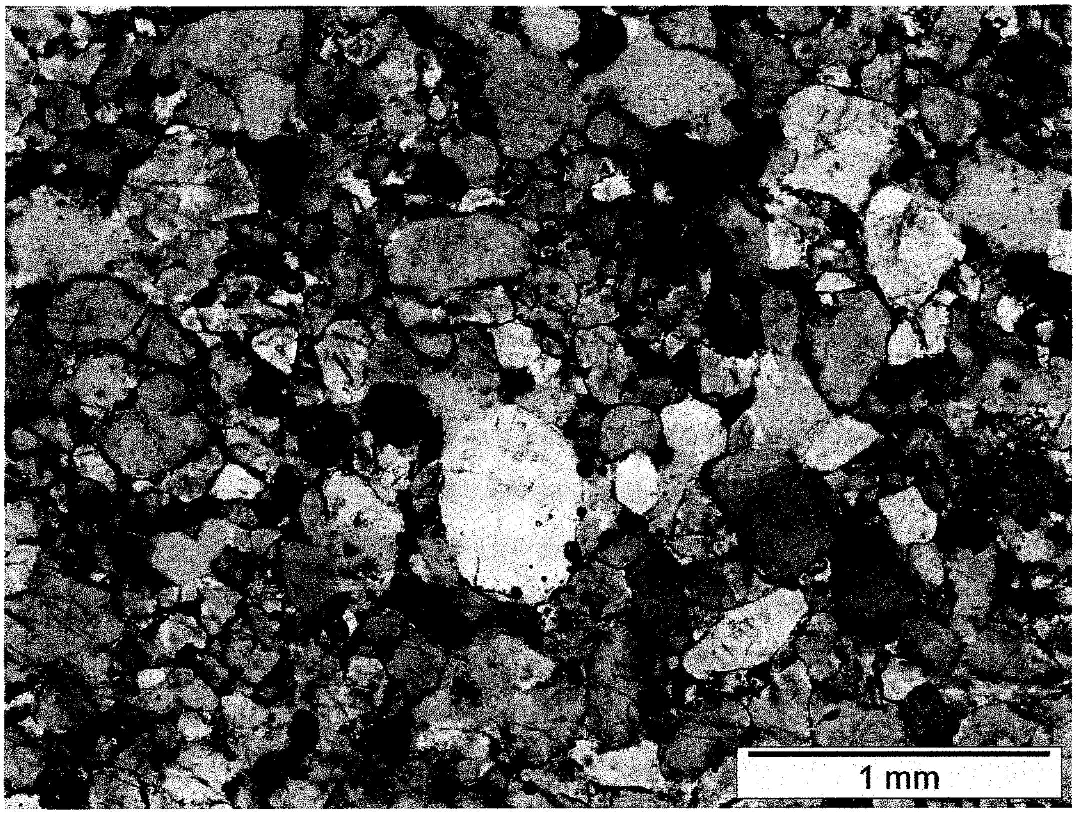


Figure 4.37: Photomicrograph of a medium-grained quartzarenite showing rounded grains, moderate sorting, tightly packed, Monocrystalline quartz is the dominant grain type. Outcrop D-10.

The predominance of these grain contact types indicates that the sandstone has undergone considerable compaction. Moreover, extensive grain fracturing provides further evidence for compaction (Figure 4.38). Compaction is related to the burial depth and results in porosity reduction. Furthermore, it suggests that, tectonic processes could be related to beds vertical position.

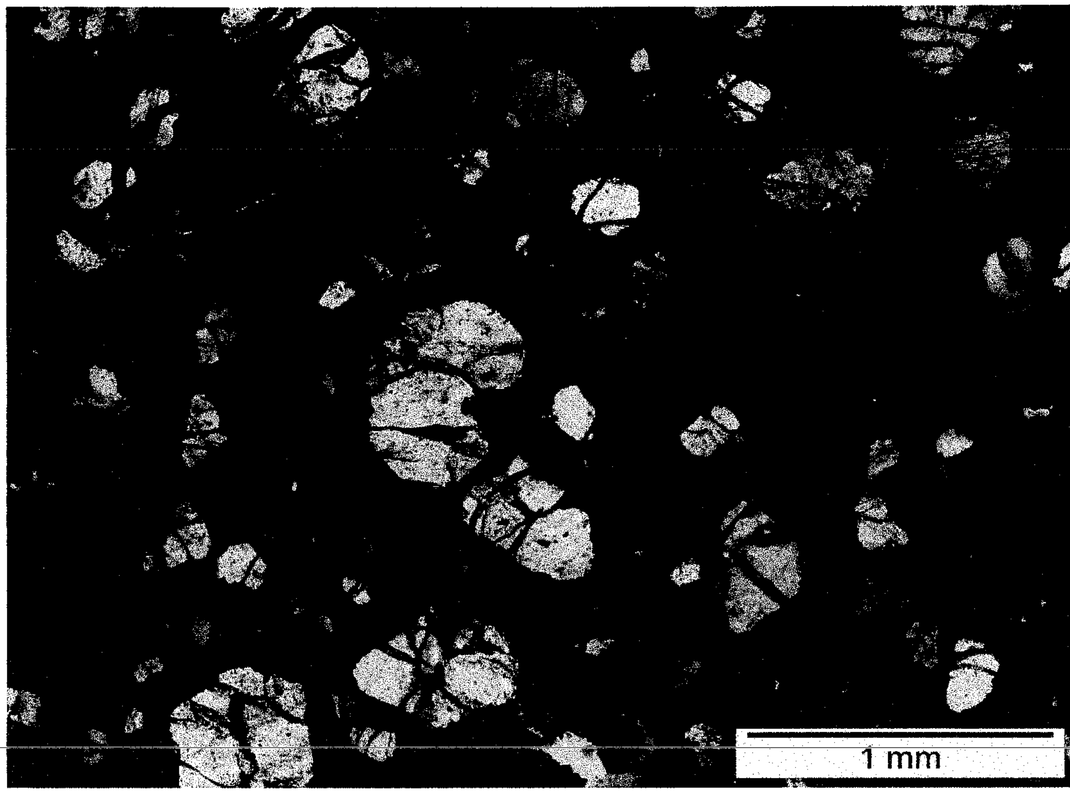


Figure 4.38: Photomicrograph of Quartzwacke, showing rounded quartz. Commonly deformed. Note the abundant iron-oxide. Outcrop A-2.

- **Cementation and Fracture infill**

The framework grains are extensively bounded by cement and matrix, dominantly quartz overgrowth, iron oxide (coating the grains), and clay matrix. The cementation recorded in the studied sandstones resulting in partial or complete filling of pore spaces.

Thin section scale microfractures have been filled with iron oxide and quartz cement (Figure 4.39). Moreover, clay infills in this sandstone are probably derived from adjacent mudstones.

- **Dissolution and precipitation**

Chemical processes in diagenesis involve dissolution and precipitation episodes which occur in the form of iron oxide concretions or nodules. Evidences of the occurrence of this phenomenon are recorded in the present study as discussed at section **4.1.5** above (weathering). These concretions are presumably digenetic in origin and formed in situ.

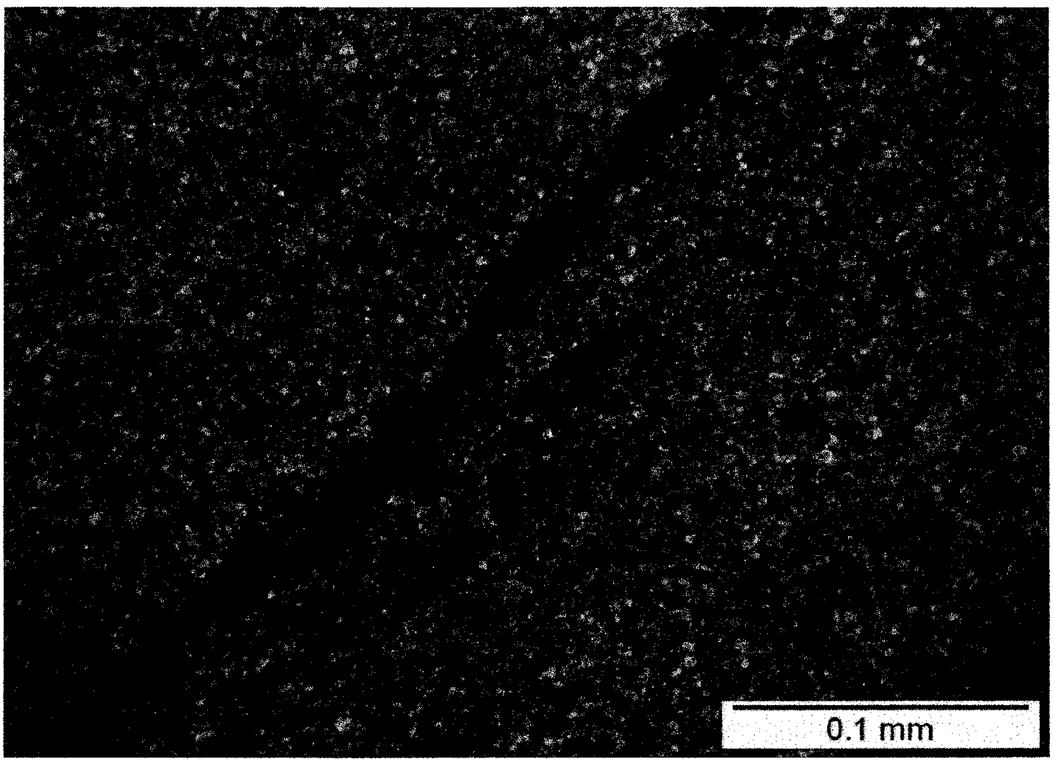


Figure 4.39: Photomicrograph showing fractures filled with iron oxides. Outcrop D-1.

4.4 DISCUSSIONS

The sedimentary rocks of the western part of Peninsular Malaysia have traditionally been divided into the calcareous series and an arenaceous series. Calcareous rocks which contain fossils have proved to be Carboniferous to Permian in age (e.g., limestone developed in Sungai Siput and in the Kinta Valley). Conversely, most fossiliferous arenaceous rocks are Triassic in age (e.g., Semanggol Formation).

Formally, the lack of sufficient palaeontological evidence of the sedimentary formation (western part of Peninsular Malaysia) is believed to be limited within the late Paleozoic and early Mesozoic eras ranging from Carboniferous-Permian-Triassic. Furthermore, it made it necessary to use lithological characteristics for mapping over large areas (Alexander, 1959).

In the last decades, it was widely accepted that the formation older than the granite consisted only of one main sequence of characteristically arenaceous rocks of Triassic age and one major sequence of characteristically calcareous rocks of Carboniferous-Permian age.

Formerly, the general rule for geological mapping in Peninsular Malaysia is to group alcareous rocks as Carboniferous and Permian in age when the strata are non-fossiliferous. Likewise, arenaceous rocks are considered to belong to the Triassic system, with the exception of some quartzites and shale which are known to be older than the limestones in Langkawi, Kedah and Perlis areas (Kubang Pasu Formation). Interbedded calcareous argillaceous rocks which contain no fossils are referred to as "the Carboniferous and Permian system". When Calcareous rocks are absent and arenaceous rocks are abundant, they are included in the Triassic system.

This method when applied to sediments in which change of facies are common and structures are dominated by regional metamorphism is unsatisfactory. Moreover, the lack of contiguity of outcrops and the absence of paleontological data, for these reasons, the exact correlation of rocks in different areas are not possible (Roe, 1951; Foo, 1983).

According to the nomenclature formally adopted by the Geological Society of Malaysia, the clastic rocks exposed west and southwest of the Kinta Valley have been classified and named the Arenaceous Series (Ingham & Bradford, 1960). Moreover, the arenaceous series have been subdivided into two lithlogical groups namely, the argillaceous facies and arenaceous facies. In addition, since there is no proof of their age, they have been assigned the Triassic period on account of their lithlogical similarity to rocks in the Triassic Semanggol Formation.

4.4.1 Sedimentary Basins

Peninsular Malaysia is divided into three onshore sedimentary basins (West Basin, Central Basin and East Basin) (Aw, 1978). The Western Basin includes most if not all, Lower Paleozoic formations as well as some Upper Paleozoic formations and covers an enormous area stretching from the Perak-Thai border southward to the state of Malacca (Foo, 1983).

In the Kinta Valley during the Paleozoic, carbonate sedimentation took place in clear seas. However, these dominant limestone depositions were interrupted by occasional influx of terrigenous clastics (muddy and sandy sediments) and these clastic sediments eventually consolidated to form shale and sandstone (Ingham & Bradford, 1960).

Wong (1991) concluded that during the late Paleozoic the Kinta Valley was essentially a stable sedimentary basin (shelf) with ongoing calcareous sedimentation interrupted by argillaceous invasions from the deeper more rapidly subsiding flank from time to time , as indicated by a thick sequence of conformable carbonate and clastic sediments of Carboniferous to Permian age (Wong, 1991).

In a recent study by Pierson et al. (2009, 2011) the palaeo-depositinal environment of the Paleozoic carbonate of the Kinta Valley was interpreted as being deposited on a broad relatively deep marine slope, dipping to the west (during late Paleozoic) as indicated by the presence of slumping structures, which suggest that the slope was dipping to the west and had a north-south strike direction. Moreover, based on the presence of commonly thinly-bedded, laminated and micritic limestone it suggests a low energy environment. The common occurrence of chert layers and chert laminae further suggests that the limestone was deposited in relatively deep water.

The interpretation by Pierson et al. (2009, 2011) of the depositional environment is in agreement with a previous studies by Wong (1991) and Ingham and Bradford (1960). However, the lateral extent of "the broad platform" of these Paleozoic carbonates deposits to the eastern part of Peninsular Malaysia appear to contradict previous studies that had established tectonic models of Peninsular Malaysia as discussed in section **2.2** and therefore still required further explanation and evidences to be accepted (Figure 4.40).

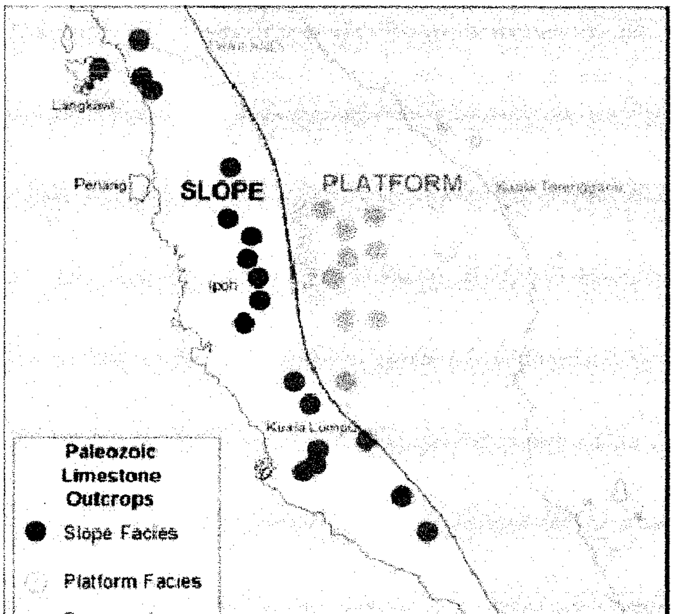


Figure 4.40: Simplified paleogeography of the Permo-Carboniferous limestone sequence, Pierson et al. (2009).

Based on our current understanding of literature and results from the present study, the observations and interpretations of sedimentary structures and rock compositions in the clastic sequence of the Kinta Valley, Kati Beds (Formation) and the rocks at Seri Iskandar are all consistent with a deep marine slope as an environment of deposition. From the tectonic setting and the depositional environment of the Kati Formation it was found that Kati Formation is regionally restricted (confined) to the slope and basin in the western part of Peninsular Malaysia.

4.4.2 Structural study

Based on the overall structural features observed in Seri Iskandar (in terms of geometry and structural style of the faults and folds), we have found a close correlation between these clastic rocks and the arenaceous and argillaceous rocks of the Kati Beds (Formation) and to some extent the structural elements of these rocks are also consistent with the limestone formations of the Kinta Valley as reported by Ingham and Bradford (1960), Gobbett (1971), Rajah (1979) and Lee (2009).

4.4.3 Seri Iskandar Part of Kati Formation

In this study we find that the Paleozoic clastic sequences formally, the arenaceous series crop out in Sungai Siput (Savage, 1937) and Kuala Kangsar in the northwestern part of the Kinta Valley (Foo, 1990, 1983). These rocks extend southward to Tapah and Teluk-Intan, Bukit Tunggal and Lumut (southern part of the Kinta Valley) (Ingham, 1938; Wong, 1991). They also crop out along the northeastern part of the Kinta Valley in Siputeh, Parit, Tanjung Tualang (Ingham & Bradford, 1960) and at Seri Iskandar near Tronoh (the present study).

A comparative study of all the clastic outcrops in the Kinta Valley and surrounding areas based on sedimentological, petrological and structural characteristics shows that the clastic sequences outcropping at Seri Iskandar are part of the Kati Formation. Moreover, our observation and interpretation (in Seri Iskandar) generally agree with previous studies by Foo (1990) and Wong (1991) in which they found that the Kati Formation lie between the granites of the Bintang and Kledang Ranges and are restricted to the western part of Peninsular Malaysia (Figure 4.41).

After careful review of previous works on clastic deposits (of all the Western part of peninsular Malaysia) it appears that the Kati Formation outcrops have been described by only two workers in the past (original work),and they are Foo (1983, 1990) and Wong (1991). Previous works on the outcrops of the Kati Formation by Foo (1990) and Wong (1991) have examined and documented in great detail the sedimentological and petrological characteristic of these rocks, as well as some general structural observations. Moreover, they interpreted the depositional environments based on sedimentary features. However, they did not present any stratigraphic column (lithologs).

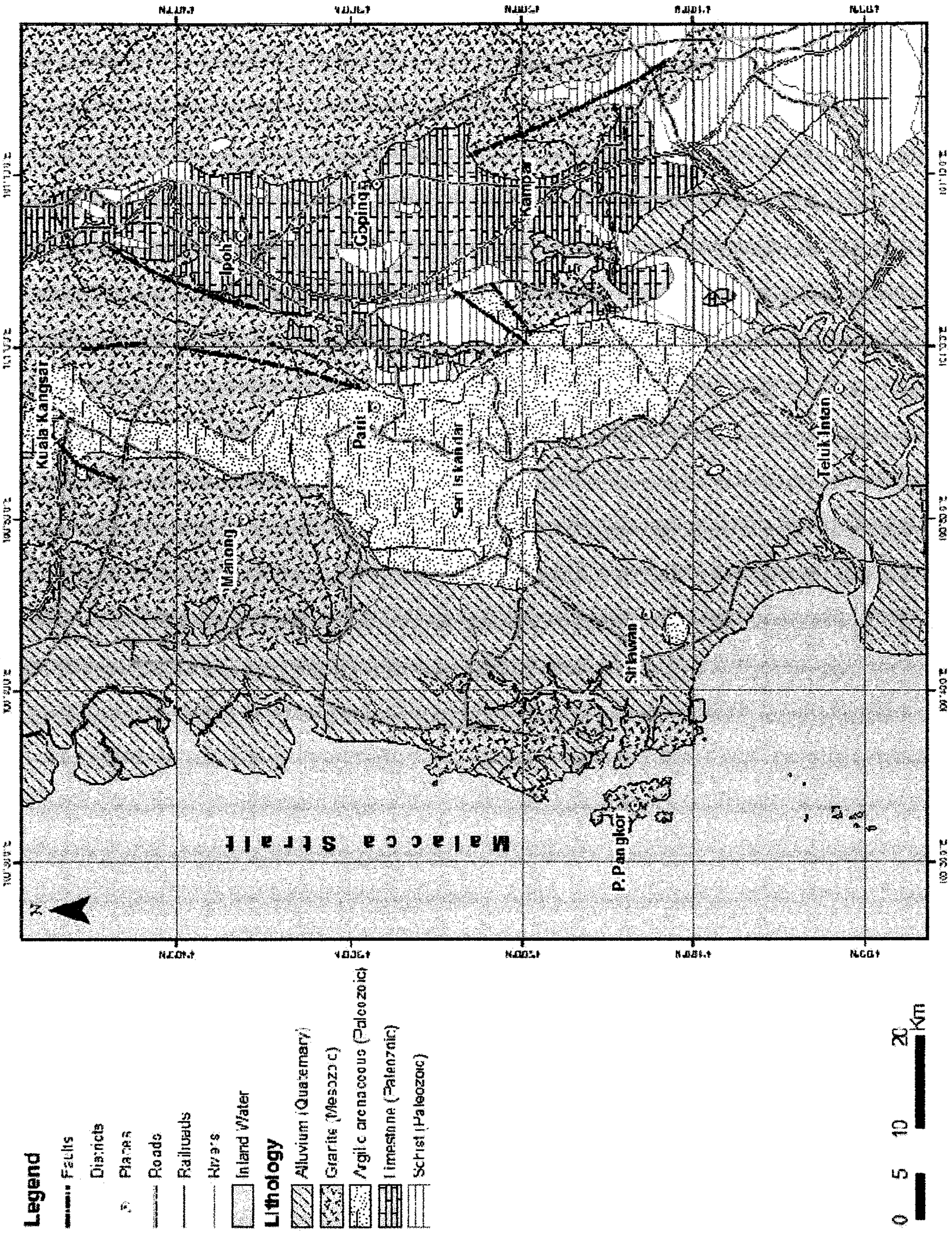


Figure 4.41: Geology of the Seri Iskandar area. Based on work by Ingham (1938), Ingham and Bradford (1960), Gobbett (1972), Foo (1983, 1990), the geological map of Peninsular Malaysia (1985), Wong (1991) and Tate et al. (2008).

4.4.4 Clastic sequences of Seri Iskandar and Kati Formation

The geologic formations in this area (the Western Zone) are poorly dated by fossils due to regional metamorphism that has affected most of the sequences (Alexander, 1959; Foo, 1983; Lee, 2009). Shale is widespread in the southwestern part Kinta Valley; however, it is devoid of fossil (Fontaine & Ibrahim, 1995).

Seri Iskandar deposits have been carefully investigated for plant remnants (fossils) which can be found in some clay or shale sequences as mentioned by Ingham and Bradford (1960). Unfortunately no fossils have been found within these deposits.

Kati Beds (Formation) are believed to be contemporaneous to the Calcareous Series (Kinta Limestone) and have been assigned a Carboniferous-Permian age based purely on lithological similarity to rocks of known age in the neighbouring areas (Foo, 1983, 1990; Wong, 1991).

In the complete absence of fossils, it is thought that no unconformity exists between the Kati Formation and Kinta Limestone and hence, the age of the rocks seem ambiguous. However, based on stratigraphic evidence and considering that Seri Iskandar clastic sequences are part of Kati Formation, these clastic deposits can be assigned a probable Carboniferous to Permian age.

4.4.5 The Stratigraphic Nomenclature "Kati Beds or Kati Formation?"

Stratigraphic principles adopted by the Geological Society of Malaysia Stratigraphy Commission require that units with different names, but which are demonstrated to be correlative, should be known by the first-published name provided that its definition and usefulness are adequate (Malaysian Stratigraphic Nomenclature Committee, 1997).

In this study, we have reviewed substantial literature on the Paleozoic stratigraphy in the western zone of Peninsular Malaysia and revised the nomenclature of the Kati Formation, changing 'Kati Beds' to 'Kati Formation' as more information have been revealed.

Foo conducted geological investigations in 1968, as part of an inventory of the natural resources of the Taiping and Kuala Kangsar area by the Geological Survey of Malaysia (currently known as the Minerals and Geoscience Department Malaysia). Foo proposed the name Kati Beds to describe a unit of sediments that occur for the most part just west of the Perak River (particularly in the Kuala Kangsar area). However, the Geological Survey of Malaysia did not publish his original work until 1990. Later, Foo published his findings in Volume 1 of the Geological Society of Malaysia in 1983; the paper entitled "The Paleozoic Sedimentary Rocks of Peninsular Malaysia-Stratigraphy and Correlation", in which he renamed Kati Beds to Kati Formation after taking into account Wong's work (which was not published at that time).

Wong conducted his geological investigations in the Lumut and Teluk-Intan area in 1973 but, his work was only published in 1991. Kati Beds was described by Wong as argillaceous and arenaceous rocks which occur in Kuala Kangsar area and extend southward along the western bank of Sungi Perak (Perak River) into Kinta Valley. Even though, this Paleozoic clastic deposit was mentioned by Foo (1990) and Wong (1991) as Kati Beds, in later publications it has been referred to as the Kati Formation by a number of authors (researchers) for instance, Metcalfe (2000), Lee et al. (2004), Lee (2009), Jasin and Harun (2011). Hutchison (2007) referred to it as "the renamed Kati Formation" but he give no further discussion. On the most recent geological map of Peninsular Malaysia compiled by Tate et al. (2008) and published by the Geological Society of Malaysia, the clastic deposits which occurred on the West-southwest part of Kinta Valley is interestingly referred to as the "Kati Formation".

Thus our definition of the Kati Formation follows that of Foo (1983) so as to avoid confusion.

In this long time lapse between the surveys of Foo (1968) and Wong (1973) and eventual publications in 1990 and 1991, there has been a rapid increase in the geological knowledge of Peninsular Malaysia and a considerable amount of work has been published on the geology of the Kinta Valley and the surrounding district for instance, Gobbett and Hutchinson (1973), Gobbett (1971), Hutchison (1977, 1989), Rajah (1979) and others. These information serve to augment the knowledge of Kati Formation.

4.4.6 Regional Correlation

There are many similarities (both lithologically and stratigraphically) between the clastic sediments of the Kubang Pasu Formation in the northwestern zone, Kenny Hill Formation in Selangor and Kati Formation in West-southwest of Kinta Valley (Foo, 1983, 1990; Wong, 1991; Hutchison, 2007). The Kati Formation is interpreted as equivalent to the Kubang Pasu Formation (Foo, 1983; Hutchison, 2007). Moreover, the Kati Formation can be correlated with the Upper Paleozoic Kenny Hill formation of Kuala Lumpur area (Wong, 1991).

4.4.7 Interpretation of Depositional Environment (in the Seri Iskandar) by the author

The depositional environment cannot be interpreted with much certainty due to lack of fossils in the Seri Iskandar deposits or the Kati Formation as discussed in section **2.2.5.5**. Hence, there is no clear relationship between the Kinta Limestone and Kati Formation (the absence of signs of unconformity exists between the Kinta Limestone and Kati Formation).Therefore, to fill the gap and help in the interpretation of depositional environments we extracted useful information from the regional geology and tectonic setting and looked at (analyzed) these clastic rocks in its stratigraphic context. The depositional environment of the clastic deposits exposed in Seri Iskandar were interpreted and put into a geologic map (Figure 4.41) based on the available sedimentological data, taking into account that the Seri Iskandar clastic rocks are part of the Kati Formation (in the context of their geological history) and placing these clastic deposits in the context with other deposits (Kinta Limestone).

Regional geological data suggest that essentially similar depositional environments have existed throughout late Paleozoic time in the Kinta Valley. Wong (1991) suggested that the clastic units (Kati Formation) sedimentation took place contemporaneously with the deposition of the carbonate rock units (Tualang Limestone which is the southwestern extension of the Kinta Limestone) and he classified both of them as Carboniferous to Permian in age. Moreover, Paleozoic carbonates of the Kinta Valley are thought to have been laid down on a broad deep marine slope, dipping to the west (Pierson et al., 2009, 2011).

Sedimentological analysis and petrographic study revealed that the Seri Iskandar clastic deposits generally show good sorting and the sequences of mudstone/shale and siltstone are characterized by fine grained textures and laminated nature. Moreover, burrow tracks have been observed within these clastic beds. The fine grain size and the thinness of the beds indicate slow deposition by fine grain sediment settling through a water column. Furthermore, the presence of sedimentary structures like thin lamination and burrow tracks indicates slow deposition in quiet water environments at depth not affected by wave motion (low energy or not intense enough to destroy the lamination). Sedimentary structures such as flame structures, graded bedding, load casts and slump features are common in these rock units. For this reason they are interpreted as related to turbidity currents (suggest the influence of turbidity currents). Moreover, the lack of wave-formed sediments and the absence of high energy structures, such as ripple marks and cross-bedding reflect deposition in relatively deep water of low energy (quiet system).

No conglomerate beds were observed within these beds and they are also unknown in the Kinta Valley which suggests that there were no coarse-grained sediments to start with (conglomerate are not available in the source). The abundance of slump structures (found within these clastic sequences and the Paleozoic carbonate of the Kinta Valley) suggest gravity-induced deposition in a lower slope environment. An analysis of these syn-sedimentary slumping structures indicates that the slope was dipping to the west and had a north-south strike direction. The overall sedimentological features suggest that these beds of clastics could be deposited on the lower part of a marine slope (dip toward the west) in the western basin.

4.4.8 Assessment of the Reservoir Quality

From the field observation and measurement of the sandstone beds exposed at Seri Iskandar, with its considerable thickness and sand properties (e.g., mineral composition and textures) in addition to the estimation of porosity and permeability from thin sections and measurement of surface core samples, these studied samples did not give any interesting porosity and permeability results. The porosity seems affected by extreme weathering and diagenetic events. In general, these sandstones show porosity/permeability reduction and even though some sandstone beds appear to have significant porosity, most of the porosity is due to surface weathering. In the otherwise weathering-resistant sandstone beds (since they are massive and composed mainly of mosaic of interlocking quartz grains) the porosity is extremely low. The reservoir quality of these samples is poor (at the surface) and perhaps the same units at depth are tight and have very low porosity and permeability values.

4.4.9 Potential as a Hydrocarbon Reservoir

Major diagenetic events observed in the Seri Iskandar sandstone include quartz overgrowth, iron-oxide cementation (coating the grains), compaction, and fracture infill. These diagenetic events generally have a negative impact on the reservoir quality (reduce porosity) (Tobin, 1997). Moreover, the compaction and quartz overgrowth cement suggest its depth of burial (at deep burial and high temperature).

For the assessment of the potential subsurface porosity and permeability and to predict the subsurface reservoir quality in this outcrop-based study (where only subsurface data available), we used a decision tree-based procedure proposed by Tobin (1997). We conclude that, these sandstones are similarly (Type-4) dominantly compacted with tight porosity. The reservoir quality represents a major risk and Seri Iskandar sandstone deposits do not qualify as analogs of a potential hydrocarbon reservoir.

Based on the depositional setting and tectonostratigraphic terranes of these clastic sequences of Seri Iskandar (which is part of Kati Formation) it was found that these clastic deposits lie between the granites of the Bintang and Kledang Ranges and are confined to the western part of Peninsular Malaysia, where hydrocarbon plays are very unlikely to be found.

On the basis of the available data which demonstrate the existence of potentially poor reservoir (probably represents a major exploration risk) and do not qualify as analogs.

We conclude that, the sandstones of Seri Iskandar would not serve as possible reservoir for the Paleozoic hydrocarbon play as proposed by Pierson et al. (2009).

4.4.10 Source Rocks

Gou et al. (2011) conducted a geochemical outcrop analogue study in Peninsular Malaysia to evaluate the potential of older Paleozoic and Mesozoic petroleum source rocks, and to see if any organic-rich intervals from the Paleozoic or Lower Mesozoic could have contributed to earlier hydrocarbon generation. This recent work has focused on the geochemistry of outcroping Paleozoic and Mesozoic sedimentary rocks from NW Peninsular Malaysia, mainly the Black Shales of Kubang Pasu formation (Beseri , Perlis) and Mesozoic age rocks from Pahang in the central part of Peninsular Malaysia (Tembeling Group and Semantan formation).

Preliminary results of geochemical characterisation of Paleozoic samples (onshore in Peninsular Malaysia), showed that the black shales of the Kubang Pasu Formation (Beseri, Perlis) (Figure 4.42) are interpreted to be of Permian age and the type of the organic matter are predominately marine. The total organic carbon (TOC) content ranged from poor to moderate (1.07 to 1.32 wt per cent). The Hydrogen Index (HI) at present day (mg HC/g TOC) is 10 to 92. The thermal maturity at present day is over mature and possibly the hydrocarbon could have generated oil previously. Based on these geochemical analyses of Paleozoic rock samples from the outcrops, the results showed organic-rich, high thermal maturity and signs of remaining hydrocarbon potential. Geochemical analyses suggest that Paleozoic sedimentary rocks from Perlis do exhibit the presence of hydrocarbons.

According to Pierson et al. (2009) the black carbonaceous shale at Batu Gajah (Figure 4.43), which forms part of the Paleozoic clastic sequences in the western part of Peninsular Malaysia is rich in organic matter. Samples collected at one of these outcrops (in Batu Gajah) have a measured Total Organic Content (TOC) greater than 6%, making it a very good source rock. Total Organic Content (TOC) data or values are not available in this study.
However, the carbonaceous shale of Batu Gajah forms part of the Paleozoic clastic sequences in the western part of Peninsular Malaysia. This Carboniferous shale is classified into the argillaceous facies within the calcareous series (Ingham & Bradford, 1960). Wong (1991) interpreted the Kati Beds (Formation) as the argillaceous and arenaceous series. Moreover, The Kati Formation is interpreted as equivalent to the Kubang Pasu Formation (Foo, 1983; Hutchison, 2007). This allows some interesting correlations with black shales from Kubang Pasu Formation and the black shales of Batu Gajah.

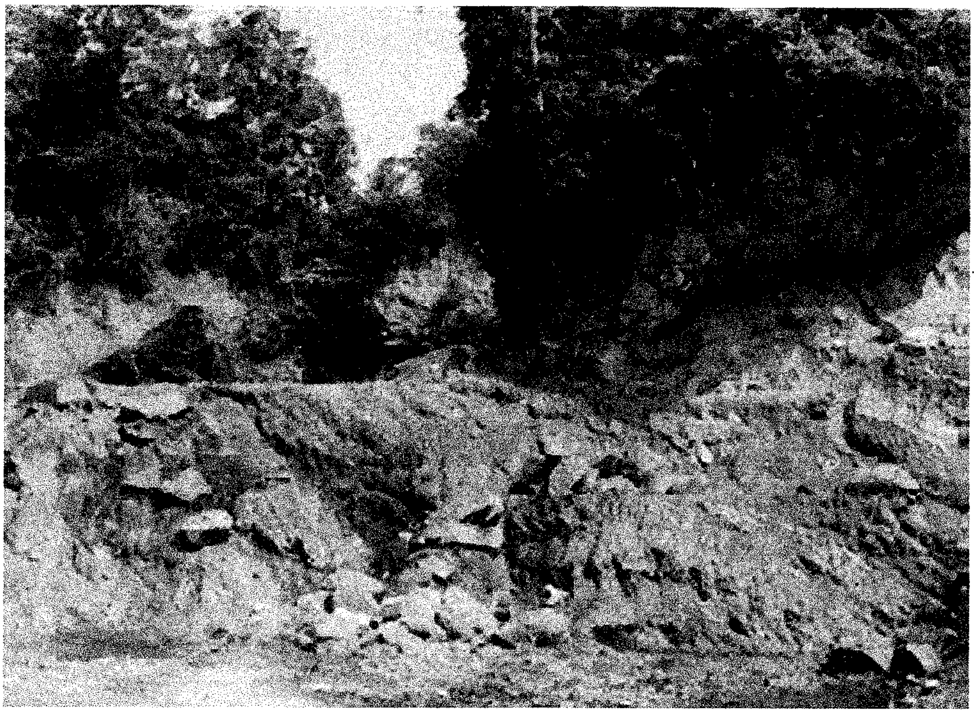


Figure 4.42: Black Shales, Beseri, Perlis, NW Peninsular Malaysia, from Gou et al. (2011).

Figure 4.43: A thick layer of black carbonaceous shale outcrops near Batu Gajah, Perak. This layer is more than 10m thick.

CHAPTER 5

CONCLUSIONS AND RECOMMENDTION

5.1 CONCLUSIONS

This is the first geological study of the clastic deposits in Seri Iskandar area. This study involved detailed sedimentology, petrology along with structural observations. The method of investigations comprised field work and laboratory analysis. This study has shown that, the clastic sequences outcropping at Seri Iskandar are part of the Paleozoic sedimentary sequences in Kinta Valley. These Paleozoic clastic sequences crop out in Sungai Siput and Kuala Kangsar in the northwestern part of the Kinta Valley and extend southward to Tapah, Teluk-Intan, Bukit Tunggal and Lumut (southern part of the Kinta Valley). They also crop out along the northeastern part of the Kinta Valley in Siputeh, Parit and Tanjung Tualang.

Based on lithologic features, sedimentary structures and bedding geometry observed in the outcrops, the clastic sequence at Seri Iskandar can be divided into four broad lithologic units, including sandstone, siltstone, mudstone and thinly interbedded sandstones, siltstones and mudstones. Primary sedimentary structures have been recognized in this clastic beds contain graded bedding, lamination, burrow tracks and slumps.

The clastic sequences crops out in Seri Iskandar are deeply weathered, commonly sandy loams over sandstone and ferruginous gravel can be encountered where shale/mudstone predominates. Furthermore, surface chemical weathering features have been found at these outcrops include concretions and nodules, Liesegang rings, Dendrites, colour mottling.

It is reasonable to consider that the weathering process of these clastic sequences is important as another factor in effecting the reservoir quality (beside the diagenesis).

Based on the results of the petrographic analysis, the sandstones of Seri Iskandar revealed variation in the sandstone classification, grain size and porosity. This sandstone is composed dominantly of cemented quartz with subordinate feldspar and minor amounts of black grains of heavy minerals. Moreover, it is consists of a high proportion of quartz grains which indicate its mineralogical maturity. The nature of sorting, roundness and high clay content suggests that the sandstones in the studied area are compositionally and texturally mature.

The framework grains were strongly bounded by cement and matrix. The most common type of cement in the Seri Iskandar samples is silica (generally in form of quartz overgrowth), whereas the iron oxides and clay matrix are less common. It is possible to find one or two or all types of cements in a rock sample.

According to McBride (1963) and Folk (1980) classification the sandstone of the Seri Iskandar area classified as quartzarenites and quartzwackes. The relationship between sandstone petrography, tectonic processes and metamorphism has been studied. The grains show both straight and sutured contacts at most grain boundaries. Some quartz grains were strongly deformed as shown by multiple sets of fractures or cleavage fractures. The predominance of these grain contact types indicates that the sandstone has undergone considerable compaction. Moreover, extensive grain fracturing provides further evidence for compaction. Compaction is related to the burial depth and results in porosity and permeability reduction. Furthermore, the facts that these beds are sub-vertical imply that the area had undergone tectonic processes which had tilted the beds. However, these clastic sequences were hardly affected by contact metamorphism (Triassic time).

Seri Iskandar deposits have been investigated for plant remnants which can be found in some clay/shale as mentioned by Ingham and Bradford (1960).Unfortunately no fossils have been found within these deposits.

Seri Iskandar clastic deposits generally show good sorting and the sequences of shale/mudstone and siltstone are characterized by fine-grained textures and laminated nature. Moreover, sedimentary structures like burrow tracks, load structures, slumps and some graded sandstone beds have been found within these clastic sequences. However, no conglomerate beds were observed, as well as the absence of high energy structures, such as ripple marks and cross-bedding. These features correspond to a quiet system. Therefore is likely to be deposited on the lower part of marine slope.

Result from the structural geology observations on Seri Iskandar outcrops revealed the probability of the effect of a tectonic activity during Triassic time. Seri Iskandar outcrops contain well-developed faults,joints, veins, infilled joints and fractures. The outcrops have been deformed in to tight folds and faults. Moreover, they appear structurally complex. Three distinct deformation events (faulting episodes) are recognized which include:sets of normal faults, sets of reverse-thrust fault and sets of conjugate fracturing.

In order to assess the possibility of the sandstones of Seri Iskandar as potential hydrocarbon reservoir rocks, an integration of Petrophysical and Petrographic investigation were carried out. Results of the assessment of the potential for these sandstones (reservoir quality) indicate that, the visual estimation of porosity from thin sections show that porosity is negligible to poor (<10%). However, core analysis of some surface cores plugs samples shows the presence of high porosity (17-24%). This high porosity is greatly enhanced by weathering processes (weathered surface). Furthermore, a couple of cores show impossibility of measuring porosity. These core samples were taken from well cemented/compacted beds. All core plugs which were cemented or well compacted and contain fractures produced permeability errors.

Petrographical study of these clastic revealed that, four main diagenetic processes affected the sandstone of Seri Iskandar include compaction, cementation, fracture infill and dissolution and precipitation. These diagenetic events generally show negative impact on the reservoir quality (reduce porosity).

From our comparative study of all the clastic outcrops at Kinta Valley and surrounding areas, based on sedimentological, petrological and structural studies, we found that, the clastic sequences outcropping at Seri Iskandar are part of the Kati Formation.

An investigation with respect to the southward and eastward extension (continuity) of the exposed Kati Formation and clastic sequences of Seri Iskandar has revealed that, the Kati Formation is located around Kuala Kangsar (the northwestern part of the Kinta Valley) lie between the granites of the Bintang and Kledang Ranges and it extends southward to Tapah and Teluk-Intan. Moreover, these Paleozoic clastic deposits were regionally restricted to the western part of Peninsular Malaysia.

In the basis of the depositional environment and tectonostratigraphic terrains of these clastic sequences of Seri Iskandar (which is part of Kati Formation), the findings of this research support the idea that, Kati Formation regionally confined to the slope and basin in the western part of Peninsular Malaysia, where hydrocarbon plays are very unlikely to be found and evidently do not extend far to the eastern part of the Peninsula.

Hence, no unconformity exists between the Kinta Limestone and Kati Formation. Moreover, no fossils have been found within the clastic of Seri Iskandar or Kati Formation and since these clastic deposits of Seri Iskandar are correlatable with the Kati Beds (part of Kati Formation); we assigned Seri Iskandar clastic rocks the same age; in the view of the Carboniferous to Permian in age assigned by Foo (1990) as well as Wong (1991).

From the field observation and measurement of the sandstone beds that are exposed in the Seri Iskandar, with its considerable thickness and sand properties, in addition to the estimation of porosity and permeability from thin sections and measurement of surface core samples, these studies did not give any interesting porosity and permeability measurement result. The porosity and permeability seems to be highly affected by extreme diagenetic conditions and alteration by recent surface weathering. Therefore, we conclude that, the results of the reservoir potential evaluation in Seri Iskandar demonstrate the existence of potentially poor reservoir (at the surface) and perhaps the same units at depth are tight and have very low porosity and permeability values. However, due to the lack of seismic and well data, we have to note that, even if poor reservoir quality exposed at the surface the possibility of having a porous counterpart in the subsurface cannot be ruled out, that originally the sandstone was clean possessing good sorting and there for was of good quality.

For the assessment of the potential subsurface porosity and permeability and predict the subsurface reservoir quality in this outcrop-based study (where only subsurface data available) we used a decision tree based procedure proposed by Tobin (1997). Even though it is difficult to assess reservoir potentially from only the just mentioned data, however, we conclude that, these clastic sequences of Seri Iskandar are similar to (Type-4) dominantly compacted with tight porosity (Tobin, 1997).

The results of this investigation show that the reservoir quality represents a major exploration risk and Seri Iskandar deposits do not qualify as analogs of a potential hydrocarbon reservoir. We conclude that, the sandstones of Seri Iskandar would not serve as possible reservoir for the Paleozoic hydrocarbon play as proposed by Pierson et al. (2009).

5.2 RECOMMENDATION FOR FURTHER STUDY

This study has documented the clastic deposits of Seri Iskandar and the outcomes of this study reduced to some degree the uncertainties on elements of the Paleozoic hydrocarbon plays and will benefit for future work on Paleozoic hydrocarbon plays. Moreover, study findings provide the following **insights for future research**.

1) Further research might explore the depositional setting and the relation between the Kati Formation and Kinta limestone formation.
2) Additional SEM and XRD analyses of Seri Iskandar sediment are needed to allow characterizing and quantifying more accurately the different mineralogical phases and evaluation.
3) Seismic surveys should be carried out in this area to correlate the results of the geological field work with seismic sections. These will provide new data to be integrated into an improved geological interpretation of Seri Iskandar area and Kati Formation.
4) Further geomechanical analyses are required to test the Total Organic Carbon (TOC) from black shales of the Batu Gajah in order to assess its potential as petroleum source rocks.

   Considering the fact that, no fossils have been found at these sites (Seri Iskandar) and a probable upper Paleozoic Carboniferous to Permian age is assigned, there remains uncertainty regarding the age and to answer the question of the exact geological age of these rocks, we strongly recommend the use of another approach to determine the age rather than fossils e.g., radioactive dating method (e.g., II U–Pb–LA– ICP– MS zircon) which would be very useful to unravel their provenance and assure the stratigraphic correlation.
5) Although some initial porosity can be lost by cementation, compaction and grain rotation, some primary porosity can be preserved in the rock (at depth); further diagenesis study will indicate whether the porosity and permeability are preserved.

6) Future tectonic and structural geology studies for these clastic sequences of Seri Iskandar will allow us to significantly improve our understanding of its vertical position.
7) The study outcome, suggested that further exploration should be focused on the Paleozoic sequence located in the Malacca strait.

REFERENCES

Abd Kadir, A., Pierson, B., Zahir, Z.T., & Chow, W. S., 2009. Kinta Valley limestone: clues for a new play?. In: AAPG Annual Convention & Exhibition, 7 - 10 June 2009, Denver, Colorado USA.

Abdullah, I., Jasin, B., Jantan, A., Samsudin, A.R., & Said, U., 1989. The Semanggol Formation post Semanggol structures and their significance to regional geology, Warta Geology, 15(1), 28-29.

Alexander, J.B., 1959. Pre-Tertiary Stratigraphic Succession in Malaya. Nature, London, 183, 203-232

American Petroleum Institute, 1956, API recommended practice for determining permeability of porous media: RP-27, Dallas, Texas.

American Petroleum Institute, 1960, API recommended practice for core-analysis procedure: RP-40, Dallas, Texas.

AW P.C, 1978, Onshore sedimentary basins of Malaysia, in: ESCAP Atlas of stratigraphy I,United Nations, New York ;13-31.

Barber A.J., Crow, M.J. & De Smet, M.J.M. 2005.Chapter 14: Tectonic evolution. In: Barber, A.J., Crow, M.J. Milsom, J.S. (eds). Sumatra: Geology, Resources and Tectonic Evolution. Geological Society, London, Memoirs, 31, 234-259.

Bates, R.L. & Jackson, J.A. 1980.Glossary of Geology. 2nd edn. American Geological Institute, Falls Church, Virginia, 749 p.

Bignell, J.D. and Snelling, N. J. 1977. Geochronology of Malayan granites. Overseas Geology and Mineral Resources, 47, Institute of Geological Sciences, H. M. Stationery Office, London, 72 pp.

Bin Leman, M. S. 1990. Permian productidina of Britain and Malaysia. Doctoral thesis, Durham University.

Bishop, M. G., 2002. Petroleum systems of the Malay Basin Province, Malaysia: U.S. Geological Survey Open-File Report 99-50-T, 21 p.

Blatt, H., Middleton, G. and Murray R., 1980. Origin of sedimentary rocks, 2nd edit., Prentice Hall Inc., New Jersey, 782pp.

Boggs, S. Jr., 1987. Principles of sedimentology and stratigraphy: Columbus, Ohio, Merrill Publishing Company, 784 p.

Boggs, S. Jr., 2001, Principles of sedimentology and stratigraphy, 3rd ed: Upper Saddle River, New Jersey, Prentice Hall, 726 p.

Boggs, S. Jr., 2009. Petrology of Sedimentary Rocks. Cambridge University, 2nd Edition, 621 P.

Boggs, S. Jr., 1995, Principles of Sedimentology and Stratigraphy: Prentice-Hall, New Jersey, 2nd edition, 774 p.

Burton, C.K., 1972. Outline of the geological evolution of Malaya. The Journal of Geology, 80, 293-309.

Burton, C.K., 1973. Mesozoic. In: Gobbett, D.J., Hutchison, C.S. (Eds.), Geology of the Malay Peninsula. Wiley-Interscience, New York and London, p. 438.

Burton, C. K., 1967, Graptolite and tentaculite correlations and palaeogeographyof the Silurian and Devonian in the Yunnan-Malaya geosyncline: Palaeont.

Chan, M. A., Ormö, J., Park, A. J., Stich, M., SOUZA-EGIPSY, V., & Komatsu, G. 2007. Models of iron oxide concretion formation: field, numerical, and laboratory comparisons. Geofluids, 7(3), 356-368

Cmakoundi, C., 2012. Geology, Geochemistry and Metallogenesis of Selected Sediment-hosted Gold Deposits in the Central Gold Belt, Peninsular Malaysia. Msc .Thesis,University of Tasmania.

Cobbing, E.J., MAllick, D.I.J., Pitfield, P.E.J. & Teoh, L.H. 1986. The granites of the Southeast Asia Tin Belt. Journal of the Geological Society, London, 143(3), 537-550.

Cobbing, E.J., Pitfield, P. E. J., Darbyshire, D. P. F. & Mallick, D. I. J., 1992. The granites of the South-East Asian tin belt. Overseas Memoir 10, British Geological Survey, London, 369 p

Cocks, L. R. M., Fortey, R. A., & Lee, C. P. 2005. A review of Lower and Middle Palaeozoic biostratigraphy in west peninsular Malaysia and southern Thailand in its context within the Sibumasu Terrane. Journal of Asian Earth Sciences,Vol. 24(6), p.703-717.

Coe, A.L., Argles, T.W., Rothery, D.A., and Spicer, R.A. 2010. Geological field techniques. London, UK: Blackwell Publishing Ltd. p. 336.

Compton, R. R., 1962. Manual of Field Geology: New York, John Wiley and Sons, 378 p.

Dutton, S.P., Laubach, S.E. & Type, R.S., 1991. Depositional diagenetic and structural controls on reservoir properties of low-permeability sandstones, Travis Peak Formation, East Texas, Transaction-Gulf Coast Association of Geological Societies, Vol.41, p. 209 – 220.

Fanani, F., Boyce, B., Wong, R., Fahrul A., and Alwyn, C., 2006. Fractured basement plays,Penyu Basin, Malaysia. Programme & abstracts, Petroleum Geology Conference and Exhibition 2006 (pp.61-62) Kuala Lumpur: Geological Society of Malaysia.

Folk, R.L. 1980. Petrology of sedimentary rocks. Hemphill Publishing Company, Austin, Texas, 182p.

Fontaine, H. 2002. Permian of Southeast Asia: an overview. Journal of Asian Earth Sciences, 20(6), 567-588.

Fontaine, H. and Ibrahim B. A, 1995. Biostratigraphy of the Kinta Valley, Perak. Geological Society of Malaysia Bulletin, vol. 38, pp. 159-172

Foo, K.Y. 1990. Geology and mineral resources of the Taiping – Kuala Kangsar area, Perak Darul Ridzuan. Geological Survey of Malaysia, Map Report 1, 145.

Foo, K.Y., 1983. The Palaeozoic Sedimentary Rocks of Peninsular Malaysia-Stratigraphy and Correlation: Workshop on Stratigraphic Correlation of Thailand and Malaysia, Vol. 1, Geological Society of Malaysia. pp. 1–19.

Fraser, T.A. & Allen, T.L., 2007. Field investigations of the Upper Devonian to Lower Carboniferous Tuttle Formation, eastern Richardson Mountains, Yukon. In: Yukon Exploration and Geology 2006, D.S. Emond, L.L. Lewis and L.H. Weston (eds.), Yukon Geological Survey, p. 157-173.

Geological Survey of Malaysia, 1985.Geological Map of Peninsular Malaysia, Scale 1:500,000, 8th ed. Geological Survey of Malaysia.

Ghani, A.A. 2009. Plutonism. In: Hutchison, C.S. & Tan, D.N.K. (eds) Geology of Peninsular Malaysia. Geological Society of Malaysia, Kuala lumpur, 211–231.

Gobbett, D. J. 1971. Joint pattern and faulting in Kinta, West Malaysia. Bulletin of the Geological Society of Malaysia, 4, 39-47.

Gobbett, D.J., & C.S. Hutchinson (Eds.) 1973. Geology of the Malay Peninsula. John Wiley & Sons, Inc., New York. 438 pp.

Gobbett, D.J. 1972. Geological map of Malay Peninsula. Scale 1: 1,000,000. Kuala. Lumpur: Geological Society of Malaysia.

Gou, P., Hassan, M. H. A., Yeow, B. S., Abdullah, W. H., & Lee, C. P. 2011. A geochemical overview of selected Palaeozoic and Mesozoic petroleum source rock analogues from outcrop studies, Peninsular Malaysia. Program book, PGCE 2011, 7-8 March 2011 (pp. 161-162). Kuala Lumpur: Geological Society of Malaysia.

Hamblin, W. Kenneth & Eric H. Christiansen 2001. Earth's Dynamic Systems. 9th ed. Prentice Hall, Upper Saddle River, N.J.: 604-605.

Hutchison, C. S. 1978. Southeast Asian tin granitoids of contrasting tectonic setting.J. Phys.Earth,26, 5221-5232.

Hutchison, C. S. 1994. Gondwanaland and Cathaysian blocks, Palaeotethys sutures and Cenozoic tectonics in South-East Asia. Geologisches Rundschau, 82, 388–405.

Hutchison, C.S. 1975.Ophiolite in Southeast Asia. Geological Society of America Bulletin,86, 797–806.

Hutchison, C.S. 2009a. Metamorphism, Chapter 11 in Hutchison, C.S. and Tan, D.N.K. (eds.) Geology of Peninsular Malaysia. Geological Society of Malaysia & University of Malaya, Kuala Lumpur, p.233–247.

Hutchison, C.S. 2009b. Tectonic Evolution, Chapter 14 in Hutchison, C.S. and Tan, D.N.K. (eds.) Geology of Peninsular Malaysia. Geological Society of Malaysia & University of Malaya, Kuala Lumpur, p.309–330.

Hutchison, C.S. 2009d. Tectonic evolution of Southeast Asia GEOSEA 2009- Eleventh Regional Congress on Geology, Mineral and Energy Resources of Southeast Asia (pp. 28). Kuala Lumpur: Geological Society of Malaysia & LESTARI.

Hutchison, C.S., 1973. Tectonic evolution of Sundaland-a Phanerozoic synthesis: Geological Society of Malaysia Bulletin., v. 6, p. 61-86.

Hutchison, C.S., 1977.Granite emplacement and tectonic subdivision of Peninsular Malaysia. Bulletin of the Geological Society of Malaysia, 9, 187-207.

Hutchison, C.S., 1989. Geological evolution of South-East Asia. Oxford Monographs on Geology and Geophysics No. 13. Clarendon Press, Oxford, 368 pp.

Hutchison, C.S., 1993. Gondwana and Cathaysian blocks, Palaeotethys sutures and Cenozoic tectonics in south-east Asia. Geologisches Rundschau 82, 388–405.
Hutchison, C.S., 1996. Geological Evolution of South-east Asia. Geological Society of Malaysia. 368p.

Hutchison, C.S., 2007.Geological Evolution of South-East Asia (2nd Edition), Geological Society of Malaysia, 433 pp.

Hutchison, C.S., 2009 c, Bentong-Raub Suture. In: Hutchison, C.S. and Tan, D. N. K. (eds.) Geology of Peninsular Malaysia. Geological Society of Malaysia & University of Malaya, Kuala Lumpur. p. 43–53.

Ingham, F.T. and Bradford E.P., 1960.The geology and mineral resources of the Kinta Valley. Perak. Geological Survey District Memoir 9, Federation of Malaya Geological Survey, Ipoh, 347 p.

Ingham, F.T., 1938. The Geology of the Neighbourhood of Tapah and Telok Anson, Perak, Federated Malay States, with an Account of the Mineral Deposits.
Ismail, N., Azwin, S. Rosli, Muztaza M., Nordiana, & A. H. A. Teh Saufia, 2012. A Study of Water Table and Subsurface Using 3-Dimensional Ground Penetrating Radar, International Journal of Environmental Science and Development vol. 3, no. 6, pp. 579-583

Jasin, B., and Harun, Z., 2011. Lower Carboniferous (Tournaisian) radiolarians from Peninsular Malaysia and their significance. Bulletin of the Geological Society of Malaysia 57, 47–54.

Jones, C.R., 1968.LowerPaleozoic rocks of Malay Peninsula. American Association of Petroleum Geologists Bulletin 52, 1259-1278.

Khoo, T.T., Tan, B.K., 1983.Geologic evolution of Peninsular Malaysia, Proceedings of a workshop on stratigraphic correlation of Thailand and Malaysia. The Geological Society of Thailand and the Geological Society of Malaysia, pp. 253–290.

Lee C.P., Shafeea Leman, M., Hassan K., Nasib B.M.,& Karim R.2004.Stratigraphic Lexicon of Malaysia .Geological Society of Malaysia, pp. 3-33.

Lee, C. P., 2009. Paleozoic Stratigraphy. In: Hutchison, C. S. & Tan, N. K. (eds), Geology of Peninsular Malaysia. The University of Malaya and the Geological Society of Malaysia, 55-86 pp.

Lee, C.P. 1992. Fossil Localities in Malaysia: Their Conservation and. Significance. Background Paper, Malaysian National Conservation Strategy. Economic Planning Unit, Kuala Lumpur.

Loh, C.H., 1992. Quaternary Geology of the Teluk Intan Area, Perak Darul Ridzuan. Geological Survey Malaysia, Quaternary Geology Bulletin III, 52 p.

Madon, M., Abolins, P., Hoesni, M.J., & Ahmad, M., 1999. Malay Basin. In: The petroleum geology and resources of Malaysia, Petronas, Kuala Lumpur, p. 173-217.

Madon,M.,Yang, J., Abolins ,P.,Hassan,R.A., Yakzan ,A.M.,& Zainal ,S. B., 2006. Petroleum systems of the Northern Malay Basin, Bulletin of the Geological Society of Malaysia, 49, 125-134.

Magoon, L.B., & Beaumont, E.A., 1999, Petroleum system, in Beaumont, E.A. and Foster, N.H., eds., Exploring for oil and gas traps: American Association of Petroleum Geologists Treatise of Petroleum Geology, Chap. 3, p. 3.1-3.34

Malaysian Stratigraphic Nomenclature Committee, 1997. The Malaysian Stratigraphic Guide, 30p.

Maravelis, A. & Zelilidis, A., 2012. Porosity-permeability and textural parameters of the Paleogene forearc sedimentary fill on Lemnos Island, NE Greece. Turkish J. Earth Sci, 21, 415-438

Marcil, J. S., Trobec, M., & Aguilera, R. 2005. Reservoir characteristics, depositional environments and potential oil/gas rates of Devonian and Silurian drilling targets in the Gaspe basin. In Quebec: Canadian Society of Petroleum Geologists Core Conference: Calgary, Canada, CD-ROM.

McBride, E.F., 1963.Aclassification of common sandstones: Journal of Sedimentary Petrology, v. 33, p. 664–669

McBride, E.F. 1987. Compaction of Norphlet sandstones, Rankin County, Mississippi. Gulf Coast Association Geological Society Transactions 37, 98–107.

Metcalfe, I. 1984. Stratigraphy, palaeontology and palaeogeography of the Carboniferous of Southeast Asia. Memoirs of the Geological Society of France,147, 107–118.

Metcalfe, I. 1988. Origin and assembly of Southeast Asian continental terranes, Gondwana and Tethys. in Audley-Charles, M.G. and Hallam, A. (Ed.), Geological Society of London Special Publication, 37, pp. 101-118.

Metcalfe, I. 1991. Late Palaeozoic and Mesozoic palaeogeography of southeast Asia.Palaeogeography, Palaeoclimatology, Palaeoecology, 87 (1), 211-221.

Metcalfe, I. 1994. Gondwanaland origin, dispersion, and accretion of East and Southeast Asian continental terranes. Journal of South American Earth Sciences, 7(3), 333-347.

Metcalfe, I. 1996 b. Gondwanaland dispersion, Asian accretion and evolution of easternTethys .Australian Journal of Earth Sciences,43(6),605-623.

Metcalfe, I. 1996a. Pre-Cretaceous evolution of SE Asian terranes. In: Hall, R. & Blundell,D. (eds) Tectonic evolution of Southeast Asia. Geological Society of London Special Publication, 106, 97–122.

Metcalfe, I. 1998. Paleozoic and Mesozoic geological evolution of the SE Asian region, multidisciplinary constraints and implications for biogeography. In: Hall R. & Holloway J.D. (eds), Biogeography and Geological Evolution of SE Asia, Backhuys Publishers, Amsterdam, 25-41.

Metcalfe, I. 2000. The Bentong-Raub Suture Zone. Journal of Asian Earth Sciences, 18, 691–712.

Metcalfe, I. 2002. Permian tectonic framework and palaeogeography of SE Asia. Journal of Asian Earth Sciences, 20(6), 551-566.

Metcalfe, I. 2006. Palaeozoic and Mesozoic tectonic evolution and palaeogeography of East Asian crustal fragments: The Korean Peninsula in context. Gondwana Research, 9(1), 24-46.

Metcalfe, I. 2011. Palaeozoic–Mesozoic history of SE Asia. Geological Society of London, Special Publication, vol. 355., pp. 7–35.

Metcalfe, I. 2013. Tectonic Evolution of the Malay Peninsula. Journal of Asian Earth Sciences. In press. doi: http://dx.doi.org/10.1016/j.jseaes.2012.12.011

Metcalfe, I., 1989. Triassic sedimentation in Peninsular Malaysia: Palaeotectonic implications. In: Abstr. 28th IGC, Washington, DC, July 9-19 1989, 2, pp. 416-417

Metcalfe, I., Sivam, S. P., & Stauffer, P. H. 1982. Stratigraphy and sedimentology of Middle Triassic rocks exposed near Lanchang, Pahang, Peninsular Malaysia.Geological Society of Malaysia Bulletin, 15, 19-30.

Mitchell, A.H.G., 1992. Late Permian-Mesozoic events and the Mergui Group nappe in Myanmar and Thailand. Journal of Southeast Asian Earth Sciences 7, 165–178.

Muhammad, R. F. &Yeap, E. B. 2002, Estimating limestone dissolution rates in the Kinta and Lenggong Valleys using the micro erosion meter: a preliminary study, GSM Annual Geological Conference 2002 .Geol Soc Bull. V. 45, p. 26-27.
Nasution, K. S., & Lubis, A. R. 2005. Kinta Valley: Pioneering Malaysia's Modern Development.Ipoh: Perak Academy.

Nichols, G., 1999.Sedimentology and Stratigraphy, 1st Ed. Blackwell Science, Oxford, 355 p.

Osadetz, K.G., MacLean, B.C., Morrow, D.W., Dixon, J. and Hannigan, P.K. 2005. Petroleum Resource Assessment, Peel Plateau and Plain, Yukon Territory, Canada, Geological Survey of Canada, Open File Report 4841, 166 p.

Perry, C. & Taylor, K. 2007.Environmental Sedimentology: Introduction, In: Perry, C. & Taylor, K. Environmental Sedimentology. Oxford: Blackwell; 2007: 1-31

Pettijohn, F., J., 1975. Sedimentary Rocks, 3rd ed. Harper and Row, New York. 628 p.

Pettijohn,F.J.,Potter,P.E,& Siever ,R.1973.Sand and Sandstone. Springer-Verlag New York. Heidelberg. Berlin. PP. 618.

Pierson, B. J., Kadir, A. A., Sum, C. W., & Harith, Z. Z. 2011. Potential Palaeozoic Hydrocarbon Plays in and around Peninsular Malaysia. In First EAGE South-East Asia Regional Geology Workshop-Workshop on Palaeozoic Limestones of South-East Asia and South China.p.100

Pierson, B. J., Kassa, S., Tsegab, H., Kadir, A. A., Chow, W. S., Hunter, A. W., & Zuhar, Z. T. H. 2011. Sedimentology of the Palaeozoic Limestone of the Kinta Valley, Malaysia. In First EAGE South-East Asia Regional Geology Workshop-Workshop on Palaeozoic Limestones of South-East Asia and South China.5-8 December2011, Ipoh, Malaysia .p.17-20

Pierson, B.J., Askury, A.K, Chow W .S. and Zuhar Z.T.2009. Paleozoic hydrocarbon Plays in and around Peninsular Malaysia: any chance of exploration success? Proceedings of the International R&D Forum, Kuala Lumpur.

Rajah SS. 1979. The Kinta tinfield, Malaysia. Geological Society of Malaysia Bulletin; 11: 111–36.

Reading, H. G. 2001. Clastic facies models, a personal perspective. Bulletin of the Geological Society of Denmark, Vol. 48, 101-115.

Reading, H.G. 1978.Sedimentary Environments and Facies, Oxford Blackwell Blackwell Scientific Publications 557pp.

Readings, H.G., 1996. Sedimentary environment processes, facies and stratigraphy. 3rd edition. Blackwell science Publ.1996,18pp.

Reinson, G.E., Lee, P.J., Warters, W., Osadetz, K.G., Bell, L.L., Price, P.R., Trollope, F., Campbell, R.I., & Barclay, J.E., 1993. Devonian gas resources of the Western Canada Sedimentary Basin; Part I: Geological play analysis and resource assessment; Geological Survey of Canada, Bulletin 452, p. 1-127.

Ridd, M.F. A. 2012. Middle Permian–Middle Triassic accretionary complex and a Late Triassic foredeep basin: Forerunners of an Indosinian (Late Triassic) thrust complex in the Thailand–Malaysia border area. Journal of Asian Earth Sciences (2012), http://dx.doi.org/10.1016/j.jseaes.2012.09.030

Roe F.W., 1951, The geology and mineral resources of the Fraser's Hill area Selangor, Perak,Pahang, Federation of Malaya, with an account of the mineral resources, Memoir No.5. Geology Survey Department, Federation of Malaya.

Savage, H.E.F., 1937. The geology of the neighbourhood of Sungei Siput, Perak, Federated Malay State, with an account of the mineral deposits.

Scholle, P.A., 1979, A Color illustrated guide to constituents, textures, cements, and porosities of sandstones and associated rocks: Tulsa, Oklahoma, American Association of Petroleum Geologists, Memoir, 28,201p.

Scholle,P.A and Spearing,D (eds.)1982. Sandstone Depositional Environment. AAPG Memoir 31, PP410

Scrivenor, J. B. 1913.The geological history of the Malay Peninsula. Quarterly Journal of the Geological Society, 69(1-4), 343-371.

Searle, M. P., Whitehouse, M. J., Robb, L. J., Ghani, A. A., Hutchison, C. S., Sone, M., .& Oliver, G. J. H. 2012. Tectonic evolution of the Sibumasu–Indochina terrane collision zone in Thailand and Malaysia: constraints from new U–Pb zircon chronology of SE Asian tin granitoids. Journal of the Geological Society, 169(4), 489-500.

Selley, R. 2000. Applied Sedimentology,San Diego, San Francisco, New York, Boston, London, Sydney, Tokyo: Academic Press.

Selley, R. C.1978. Ancient Sedimentary Environments and their sub-surface Diagnosis, 2nd Edition. Cornell Universty Press. New York, 304 PP.

Selley, R.C. 1985. Ancient Sedimentary Environments (3rd ed.). Chapman and Hall, London, 317 p.

Shahar, S., 2005. The Prospectivity of Fractured Basement Play of the Malay Basin. Programme & abstracts, Petroleum Geology Conference and Exhibition 2005 (pp.42) Kuala Lumpur: Geological Society of Malaysia.

Sone, M., & Metcalfe, I. 2008. Parallel Tethyan sutures in mainland Southeast Asia: New insights for Palaeo-Tethys closure and implications for the Indosinian orogeny. Comptes Rendus Geoscience, 340(2), 166-179.

Stow, D.A.V., 2005, Sedimentary Rocks in the Field: A color Guide. Manson Publishing. London, 320 pp.

Suntharalingam, T.1968. Upper Palaeozoic stratigraphy of the area west of Kampar, Perak.Geological Society of Malaysia Bulletin, vol. 1, pp. 1–15.

Tan D.N.K., 2009. Oil and gas, Chapter 16.IN: C.S. Hutchison &D.N.KTan (Eds.), Geology of Peninsular Malaysia, University of Malaya and Geological Society of Malaysia. Kuala Lumpur, 365-405.

Tate, R.B., Tan, D.N.K. & Ng, T.F., 2008. Geological Map of Peninsular Malaysia.Scale 1:1 000 000. Geological Society of Malaysia & University Malaya.

Terry, R.D., Chilingar, G.V., 1955. Percent Coverage Comparison Charts. Journal of Sedimentary Petrology; 24(3):229-24.

Tjia, H.D., 1999b. Pre-Tertiary Hydrocarbon Potential. in The petroleum geology and resources of Malaysia: Petronas, Chapter 26, p. 605-635.

Tjia, H.D., 2010. Growing evidence of active deformation in the Malay basin region. Geological Society of Malaysia, Bull. 56, p. 35-40.

Tjia, H. D., 1999a. Geological setting of Peninsula Malaysia, in The petroleum geology and resources of Malaysia: Petronas, p. 139–170

Tobin, R.C. 1997. Porosity prediction in frontier basins: a systematic approach to estimating subsurface reservoir quality from outcrop samples. In: Kupecz, J.A., Gluyas, J. & Bloch, S. (eds), Reservoir Quality Prediction in Sandstones and Carbonate.American Association of Petroleum Geologists Memoir 69, p.1-18.

Tucker, M. E., 1996. Sedimentary Rocks in the Field, 2nd Ed. John Wiley and Sons, New York, NY.153 p.

Tucker, M. E., 2003, Sedimentary Rocks in the Field (Geological Field Guide), 3rd ed: Wiley, 244 p.

Tucker, M.C., 1988, Techniques in sedimentology, Blackwell scientific publ., 394p.

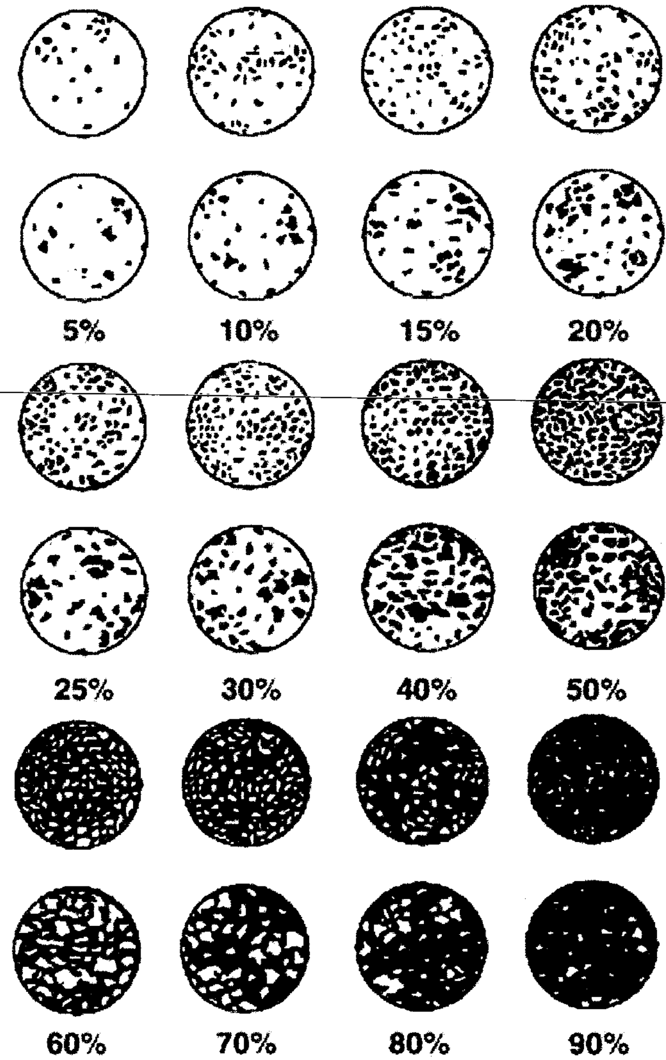
Ueno, K. & Hisada, K. 1999.Closure of the Paleo-Tethys caused by the collision of indochina and Sibumasu (in Japanese). chikyu monthly, 21, 832-839

Walker, R. G. 1984. Turbidites and associated coarse clastic deposits. In Facies Models, ed. R. G. Walker. Geoscience Canada Reprint Series 1:171-188.

Walker, R.G., 1979. Turbidites and associated coarse clastic deposits. In: R.G. Walker (Editor), Facies models. Geol. Assoc. Canada (Waterloo), 91-104.

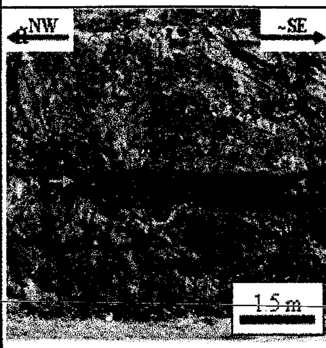
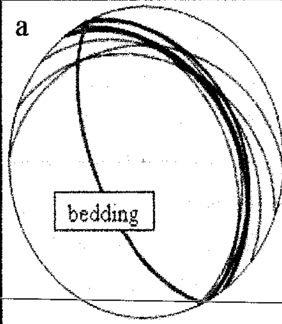
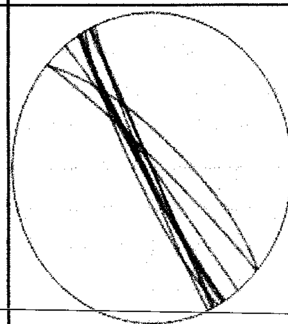
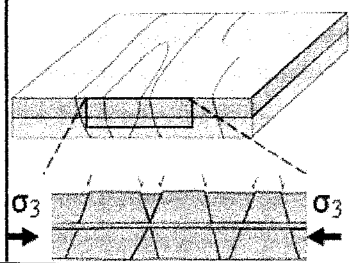
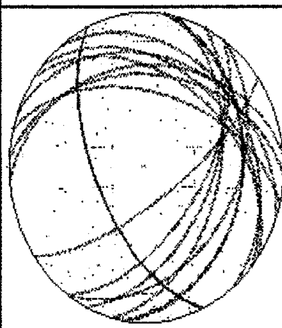
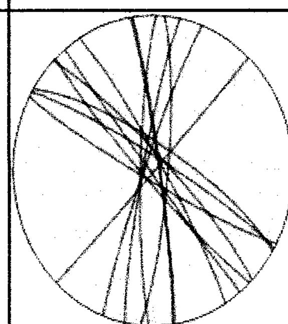
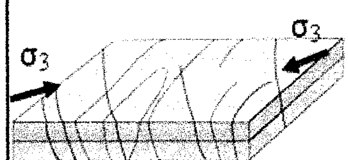
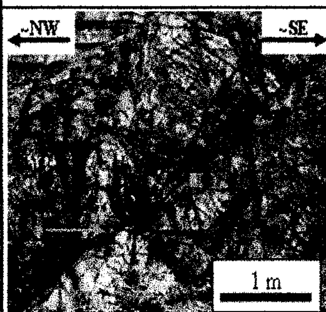
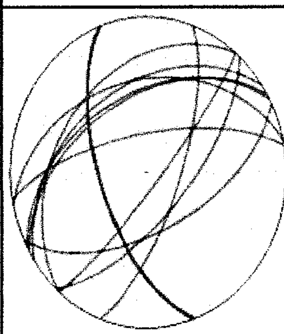
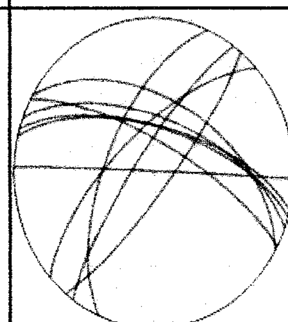
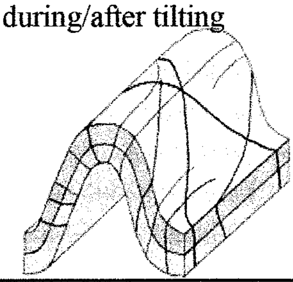
Wong T.W., 1991. Geology and mineral resources of the Lumut-Teluk Intan area, Perak Darul Ridzuan. Geological Survey of Malaysia. Map Report 3, Geological Survey Laboratory, Ipoh, Perak, pp. 96.

APPENDIX A



Comparison charts for visual estimation of coarse fragments (modified from Terry and Chilingar 1955).

APPENDIX B

Fracture	Outcrop's image	Stereonet		Structural style, formation timing and model
		Current position	**Unfold bedding**	
Normal faults (A)		a 		Extension, before tilting 
Normal faults (B)				Extension, before tilting 
Faults (C)				Compression/extension, during/after tilting 

Summary of three main sets of fractures (faults) are observed in Outcrop [D] at Seri Iskandar and the proposed formation timing and model.

PUBLICATIONS

Alkhali, H.A, Chow, W.S, Pierson, B.J, 2012. Assessment of the Paleozoic clastic deposits of Seri Iskandar as an element of a hydrocarbon system as potential hydrocarbon reservoirs: proceedings of the second international conference on integrated petroleum engineering and geosciences (ICIPEG 2012), June 12-14, 2012 (pp.57-58), Kuala Lumpur, Malaysia.

Alkhali, H.A, Chow, W.S, 2013. Sedimentology of the Paleozoic clastic deposits of Seri Iskandar. The Annual Postgraduate Conference (APC) June 27-29, Universiti Teknologi PETRONAS, Tronoh, Perak, Malaysia.