GeoJournal of Tourism and Geosites Year **IX**, no. **1**, vol. **17, May 2016**, p.**66-83**
ISSN **2065-0817**, E-ISSN **2065-1198** Article no. **16106-173**

PETROLEUM GEOLOGY-RELATED SITES IN AND AROUND MIRI, SARAWAK, MALAYSIA: POTENTIAL GEOTOURISM RESOURCES

Dony ADRIANSYAH*
Geoscience Programme, Faculty of Earth Science,
University Malaysia Kelantan (UMK) Jeli Campus, Locked Bag No. 100, 17600 Jeli,
Kelantan, Malaysia, e-mail: dony_geology@yahoo.com.my

Yuniarti ULFA
Geophysics Programme, School of Physics, University Sains Malaysia, 11800 USM,
Penang, Malaysia, e-mail: yuniarulfa@gmail.com

Illiya AMALINA A.R.
Department of Applied Geology, School of Engineering and Science, Curtin University Sarawak,
CDT 250, 98009 Miri, Sarawak, Malaysia, e-mail: illiya.amalina@curtin.edu.my

Ting KING-KING
Sarawak Shell Berhad, 1 Jalan Pantai, 98009 Lutong, Sarawak, Malaysia,
e-mail: king-king.ting@shell.com

Abstract: This paper discusses the petroleum geology-related sites in and around Miri, in the state of Sarawak, Malaysia and their potentials as geotourism resources. Desk study was conducted by reviewing some literatures related to the topic and the study area. A field visit was conducted in May 2014 to observe the recent situation of all sites in details. There are some geological/natural and man-made features in and around the city which are closely related to petroleum geology. The Canada hill (anticline), a unique tectonic feature which emerged from the surrounding coastal plain, is a petroleum trap and used to be the location of many oil wells. On top of this hill is the location of the first oil well (called "the Grand Old Lady") and Miri Petroleum Museum. The deltaic sandstone outcrops of Miri Formation (such as the Airport Road outcrop and other outcrops around Miri) are very ideal outcrops of sandstone reservoirs. Oil seeps, mud volcanoes, and oil sands are some evidences of petroleum occurrences in and around the city. Niah Caves can be seen as an analogue of carbonate reservoirs. All these sites and features can attract people to visit the city, not only geologists and geology students who want to study the petroleum geology of Miri area, but also the common people who are interested in such a field.

Key words: Petroleum geology, geotourism, geosite, Miri, Sarawak

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* Corresponding author

INTRODUCTION

Miri, the second largest city in the state of Sarawak, Malaysia, has been gazetted as Malaysia's city of petroleum. It is the birthplace of Malaysia's petroleum industry where the first oil well in the country was drilled in the city in 1910. The oil discovery has changed the face of Miri from a small fishery village into a modern city (Sorkhabi, 2010). It also contains many interesting geological and man-made features that related to its petroleum occurrences.

These features are potentials to attract people especially geologists and geology students to study the petroleum geology from the city. Common people can also enjoy these unique and interesting features while getting the knowledge on such a field. This study began from an idea that the authors hope to see Miri as the city where people can study petroleum geology in details and directly from the sites. Since the city contains numerous petroleum geology-related sites, it can be assumed as the "field laboratory" of petroleum geology in Malaysia. These sites are also potentials to become geotourism resources in the city.

Geotourism is a concept for tourism development all over the world. According to Newsome & Dowling (2005), geotourism in the field of geology is defined as a specialized form of tourism in that the focus of attention is the geosites. Geosites are based on geodiversity, such as minerals, rocks, fossils, landforms, landscapes, or other georesources. Through geotourism, we hope a better understanding of the Earth can be achieved so that its geological attractions can be acknowledged. This study aims to expose and provide as much as possible information on some petroleum geology-related sites in and around Miri and to discuss their potentials for geotourism purposes.

STUDY AREA

This study was conducted in Miri and its vicinity. Miri is a city in the state of Sarawak, East Malaysia, in the island of Borneo. It is located in the northeast coast of Sarawak and adjacent to the neighbouring country, Brunei Darussalam (Figure 1). The city is the birthplace of Malaysia's petroleum industry, which remains as its major industry until now. The city is the location where the first oil well in Sarawak and Malaysia was drilled in 1910. Geologically, Miri is composed of the deltaic deposits of the ancient Baram Delta. The modern Baram Delta is the oil-rich delta which shares its area to the state of Sarawak (Malaysia) and Brunei.

MATERIALS AND METHODS

Many studies on geosites/geomorphosites from an area for geotourism development can be referred mainly for their materials and methods, such as study on geosites in Jeli District, Kelantan, Malaysia (Adriansyah et al., 2015), geomorphosites from the Central Sector of the Ceahlău National Park, Romania (Comănescu & Dobre, 2009), and geosites/geomorphosites in Northern-Central Italy (Piacentini et al., 2011).

Materials of the research include maps, photographs and literatures related to the study area, petroleum geology, and geotourism. Methods comprise desk study and field study. Desk study required efforts to perform literature study about the topic and the study area. Field study has been conducted during a trip in May 2014 organized by Faculty of Earth Science, Universiti Malaysia Kelantan to see the actual situation and condition of all sites that related to petroleum geology in and around Miri.

GENERAL GEOLOGY AND TECTONIC SETTING

According to Madon (1999), the Sarawak continental margin forms part of the Sunda Shelf. Part of it continues on land to be exposed between Sibu and Miri and further northeast into the Inboard Belt of the Sabah Basin. Onshore Sarawak may be subdivided into three tectonostratigraphic zones that represent decreasing stratigraphic and structural complexity: Kuching Zone, Sibu Zone, and Miri Zone.

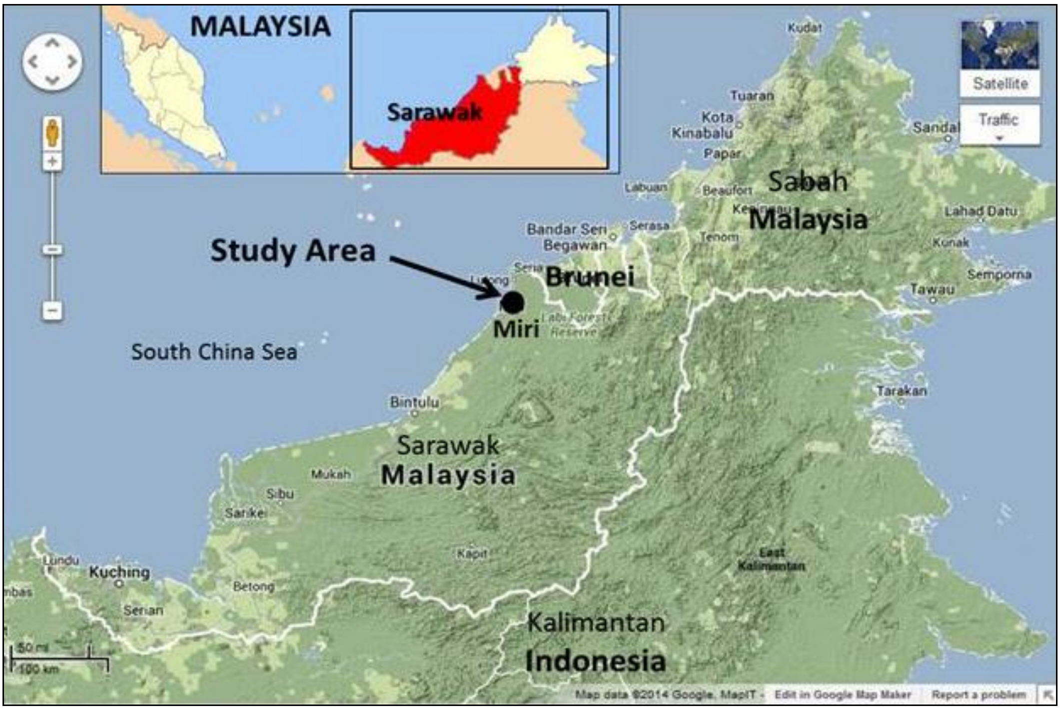

Figure 1. The location map of Miri city, Insert: Map of Malaysia (Source: Google Maps, 2014)

Figure 2. Onshore tectonostratigraphic zones of Sarawak (Source: adopted from Madon, 1999)

These three zones are bordered by Lupar Line and Tatau-Mersing Line (Figure 2). The Miri Zone is underlain by Upper Eocene to Recent strata representing the youngest of the three tectonostratigraphic zones. The Miri Zone represents the onshore extension of the Sarawak Basin that developed during the Late Eocene on the uplifted active continental margin formed by the Kuching and Sibu Zones. Miri area is located in the West Baram Delta, the western part of the Baram Delta province (in the Sarawak Basin) which is roughly triangular in shape. According to Tan et al. (1999), the West Baram Delta is characterized by the deposition of a northwestward prograding delta since Middle Miocene times. Periods of delta outbuilding were separated by rapid transgressions, represented by marine shale intervals that form the base of eight sedimentary cycles in the Sarawak Basin.

Stratigraphically, Sarawak is mostly composed by sedimentary rocks, only some igneous bodies scattered in some parts of the state. According to Hazebroek & Abang Kashim (2006), the huge amount of sand and shale making up the delta was originally from the erosion of Sarawak's interior mountain ranges. Sarawak Shell geologists have shown that this delta reach a tremendous sediment thickness, exceeding 12,000 m in the delta. The major part of the delta built up from 15 to 2 million years ago (Middle Miocene to Pliocene), but the growth of the delta continues today (Figure 3).

According to Tan et al. (1999), the Tertiary rocks of onshore northwest Sarawak consist of a thick succession of sand-shale sequences with subordinate carbonates. These rock units can be subdivided into two parts, mainly based on their degree of deformation, namely (1) an older, deformed sequence of clastic and subordinate carbonates (Late Cretaceous to Early Miocene), and (2) a younger, more gently deformed series of progradational deltaic sediments (Middle Miocene to Quarternary). The older sequences (Paleogene to early Neogene) occur in the more interior parts of Sarawak, whereas the younger sequences (upper Neogene) of deltaic series crop out extensively in the coastal areas and extend into the offshore.

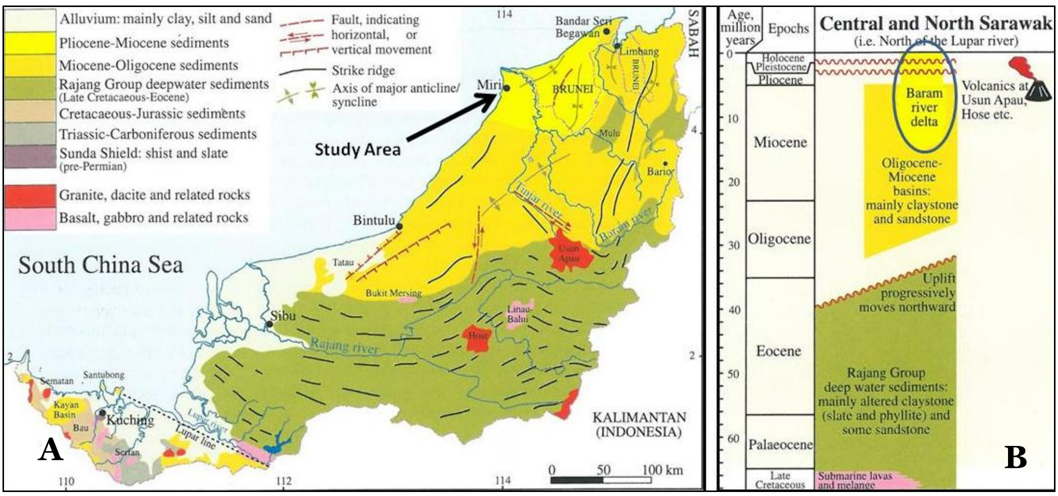

Figure 3. Regional geology of Sarawak: (A) General geology of Sarawak. Miri is a part of the Baram Delta, (B) This delta is composed of Miocene – Pliocene sedimentary rocks
(Source: adopted from Hazebroek & Abang Kashim, 2006)

Four formations in the younger Neogene succession, namely the Setap Shale, Lambir, Tukau, and Miri Formations have been studied by previous researchers, such as Tan et al. (1999) and Muol & Daud (2012), and can be summarized as follow:

- The Setap Shale Formation (Early Miocene – Quaternary) consists mainly of shales with occasionally less indurated, relatively monotonous clay intervals and thin, mainly turbiditic sandstone beds. The characteristic facies persists into the offshore area, where it gets progressively younger in the northwesterly direction.
- The Lambir Formation (Middle – Late Miocene) consists predominantly of sandstones and shales with minor limestones and marls. The Lambir, in general, has a slightly diachronous transisional contact with the underlying Setap Shale. In the Lambir Hill area, however, an erosional contact with the Setap Shale is observed.
- The Tukau Formation (Middle – Late Miocene) occupies the southern part of Miri city and extends beneath the alluvium in the eastern part of the area. Generally, the Tukau Formation consists of alternations of softer sandstones and shales rich in lignitic materials, forming an undulating topography.
- The Miri Formation (Middle Miocene) crops out around Miri and restricted to Canada Hill extending from Tanjung Lobang to Pujut. This formation provides an invaluable surface analogue for the subsurface sediments of the offshore West Baram Delta. Its outcrops are restricted to the narrow coastal region around Miri. The maximum total thickness of the Miri Formation estimated to exceed 1830 m (6000 ft). The Lower Miri unit consists of interbedded shales and sandstones, and passes downwards into the underlying Setap Shale Formation. The upper Miri unit is more arenaceous, consisting of rapidly recurrent and irregular sandstone-shale alternations, with the sandstone beds passing gradually into clayey sandstone and sandy or silty shale. This formation has been moderately folded in a northeast direction to form a wide anticline of the Miri Hill/Ridge. The regional strike of this formation is parallel to the ridge.
- Quaternary deposits are widespread on the eastern and western parts of Miri area. The deposits cover most of the underlying and low-lying areas and consist of alluvial and terrace deposits. Alluvial deposits are composed of clay and sand intermittently overlain by peat swamp in the eastern part. Terrace deposits which are found along the Miri Ridge, immediately east of the city contain remnants of sand and gravel and are found resting on shale and sandstone dipping towards the northwest close to Tanjung Lobang cliff.

The Miri area consists of a swampy alluvium plain raising a few meters above mean sea level and extends along most of the coastline. The coastal plain is relatively narrow in the city centre and in the south, but extends broadly in the north. The hilly area of Miri Hill runs to NE-SW direction forming the highest elevation in the area. The extensive alluvial plain to the east flanks the Miri Ridge and comprises peat swamp forest. The topography in the southern part of the area is undulating (Muol & Daud, 2012). Some outcrops in Miri area (onland) were exposed naturally by geological processes including of tectonic uplift and erosion. Some others were exposed by human activities, primarily by cutting the hills for housing construction projects. These human activities give both positive and negative impacts towards the outcrops in Miri and its vicinity, since these activities can provide excellent and fresh outcrops for geological studies, but the rampant construction projects will threaten some other existing outcrops.

The geological map of Miri area has been constructed by von Schumacher in 1940 which is still relevant and can be used to date (Wannier et al., 2011). This map shows that Miri area is composed of sedimentary rocks and sediments (Figure 4). The area is mostly composed of the interbedded deltaic sandstone and shale.

Some petroleum geology-related sites for geotourism resources

This study has managed to identify some petroleum geology-related sites in and around the city of Miri as potential resources for geotourism, as follow:

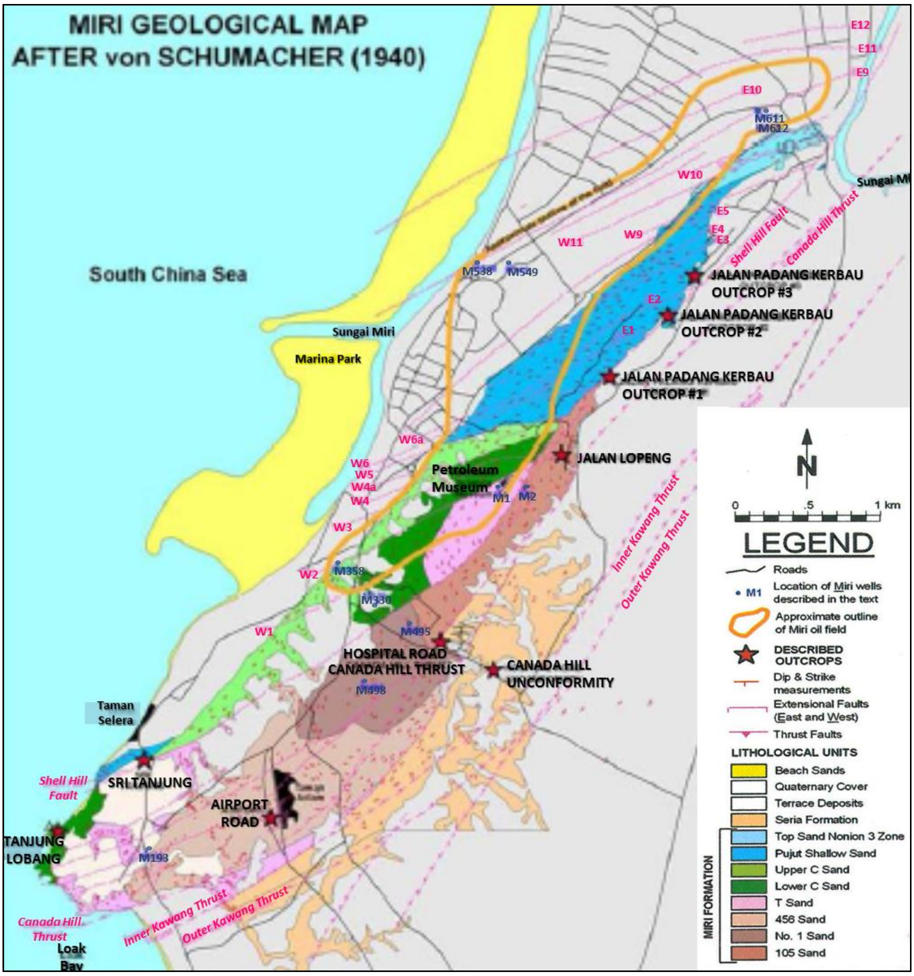

Figure 4. Geological map of Miri which was constructed by von Schumacher in 1940 (Source: Wannier et al., 2011)

The Canada Hill (anticline)

The Canada Hill or the Miri Hill (renamed in Malay as "Bukit Telaga Minyak" in 2005; Figure 5) is a narrow and elongated hill which is formed by tectonic force and oriented in NE-SW direction from Tanjung Lobang in SW to Pujut in NE. Geologically, the hill is an asymmetric, northeast-trending anticline with a gentle northwest flank and a steep and partly overturned southeast flank. According to Kessler & Jong (2012), Miri's Canada Hill is some 7 km long and less than 2 km wide and emerges from the coastal plain. The inner core of the Canada Hill, an elongated sliver of mildly folded sandstone, is bounded by the Shell Hill Fault and the Canada Hill Thrust. In this anticline, 612 wells were drilled on the NW side, but none on the SE side. This anticline was dissected by many faults to form numerous small compartments of petroleum trap.

According to Tan et al., 1999, the Miri anticline underwent two phases of deformation: firstly, a Late Miocene extention, which resulted in the Shell Hill Fault and the associated listric and antithetic normal faults; and secondly, a Pliocene compression which resulted in development of the anticlinal feature and the Canada Hill Thrust.

This hill offers visitors the excellent views of Miri and the surrounding areas. On top of the hill, people can visit two important landmarks of Miri, the Malaysia's first oil well, known as the "Grand Old Lady" and Petroleum Museum. The "Grand Old Lady" Well-1 (coordinates: N 04°23'20.13", E 113°59'42.04") is the first producing rig, however, it is no longer production and has been declared as a historical site by the government of Sarawak. It represents an important monument in the history of petroleum industry in Malaysia. According to Sorkhabi (2010), the well derrick is 30-m high and has produced 658,650 barrels of oil over period of six decades. This well also becomes the witness how Miri develops from a fishery village in the 19th century to a modern city. Shell (2013) recorded that the well was discovered by Shell in 1910 and was spudded on 10 August that year, and began producing 83 bopd in December.

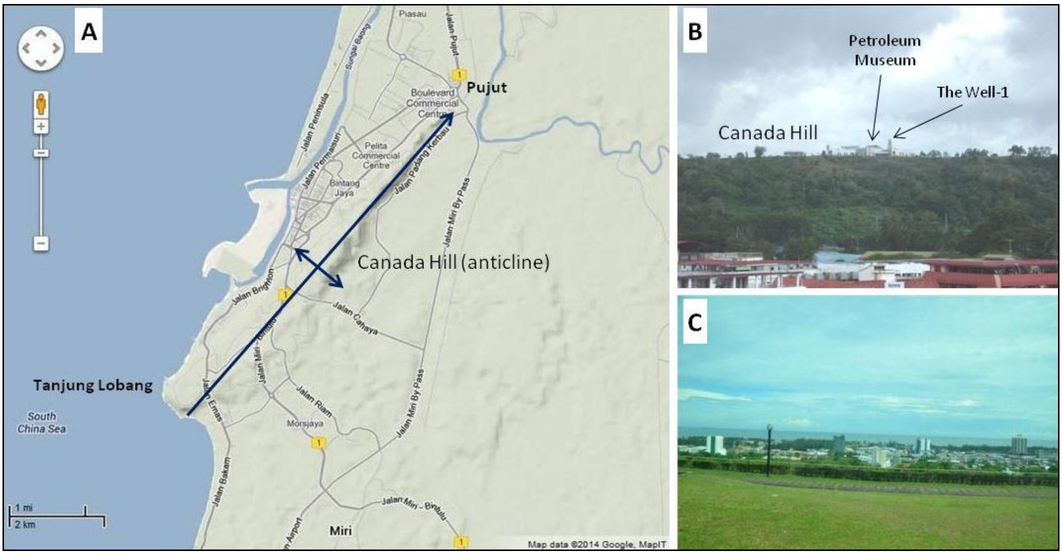

Figure 5. The Canada Hill or Bukit Telaga Minyak in Miri is an anticline: (A) The anticline extends from Tanjung Lobang to Pujut, trending to NE (Source: from Google Maps 2014), (B) The hill emerged from the surrounding coastal plain. The "Grand Old Lady" Well-1 and Miri's Petroleum Museum are located on top of the hill, (C) A view of Miri town from the top of the hill

Miri's authority and the Sarawak Museum Department, with the support from PETRONAS (Malaysia's national petroleum company) and Shell Malaysia (one of world's petroleum giants operating in Malaysia), opened a petroleum museum at the Canada Hill to preserve the records of the development of petroleum industry in Miri, Sarawak, and all Malaysia. This museum was built at the site of the Grand Old Lady and was officially opened to public in 2005. Inside of the museum, visitors can enjoy various exhibits related to petroleum discovery and industry. Visitors can also interact with the devices and technology used in petroleum industry. This museum gives opportunity to visitors mainly students and the young generation to understand the history of petroleum exploration activities in Malaysia. Both the Well-1 and the Petroleum Museum have become attractions for tourists and students (Figure 6).

The deltaic sandstone outcrops of Miri Formation

The Upper Miocene deltaic sandstone beds are the reservoir rocks in the Miri Field. These units of Miri Formation are deposited by the paleo-Baram Delta. The delta has been constantly changing and evolving throughout geological time. The modern Baram Delta can be observed as a cuspate type of delta which has one distributary (the Baram River) taking sediment into the flat coastline with the wave action hitting it and pushing the sediment back on both sides of the distributary mouth. Some excellent outcrops of deltaic sediments can be observed in and around Miri city, such as outcrops in the Airport Road, Hospital Road, Lopeng Road, and Padang Kerbau Road.

Figure 6. The "Grand Old Lady" Well-1 and Petroleum Museum in Miri, Sarawak: (A) The derrick of Miri Well-1 is now one of the landmarks of Miri city, (B) The statue of workers in the oil well/rig, (C) A model of a "nodding donkey" which is used by the petroleum industry to pump crude oil, (D) The Petroleum Museum is located on the top of the Canada Hill, next to the Well-1, (E) An exhibit inside the museum, (F) A model of an oil platform is displayed in the museum

According to van der Zee & Urai (2005), the Miri Formation is a stack of deltaic cycles forming a layered clay-sand sequence (85% sand and 15% clay) with laterally discontinuous sand bodies. Most clay layers are thin (~10 cm) with a few thicker layers (up to 50 cm thick). Felix Tongkul (2005) has identified four outcrops of the Miri Formation along the Canada Hill area. The first outcrop is the Airport Road Outcrop, a spectacular outcrop along the main road showing large scale block faulting. The second outcrop is located near the Hospital Road, extending along a 20-m high cliff which follows the Canada Hill transpressional thrust zone. The third outcrop is on the Lopeng Road, characterized by aggrading shallow marine clastics. The fourth outcrop is in Pujut, characterized by two major lithostratigraphic units of the Miri Formation, a lower and an upper sandy sequence.

The Airport Road Outcrop (coordinates: N 04°21'51", E 113°58'43") is located towards the southwestern end of the Canada Hill, along the road to the Miri Airport and around 3 km south of the Miri town centre. This outcrop represents a good example of well-preserved faulted sedimentary rock sequence analogue to reservoir rocks, seals, and structural traps in the Miri's subsurface. The outcrop exposes soft rocks including sandstones, which are the most common, and shales, mudstones, and siltstones. The sandstone units of the Miri Formation have ever become good quality reservoirs in the Miri Field before the oil field was shut down. The individual beds of sandstones in the area show different lateral thicknesses, grain sizes, and sedimentary structures. The outcrop is the first geosite which has been set up as an outcrop museum in Malaysia (Figure 7). This famous outcrop has also been studied in various geological aspects by many geologists.

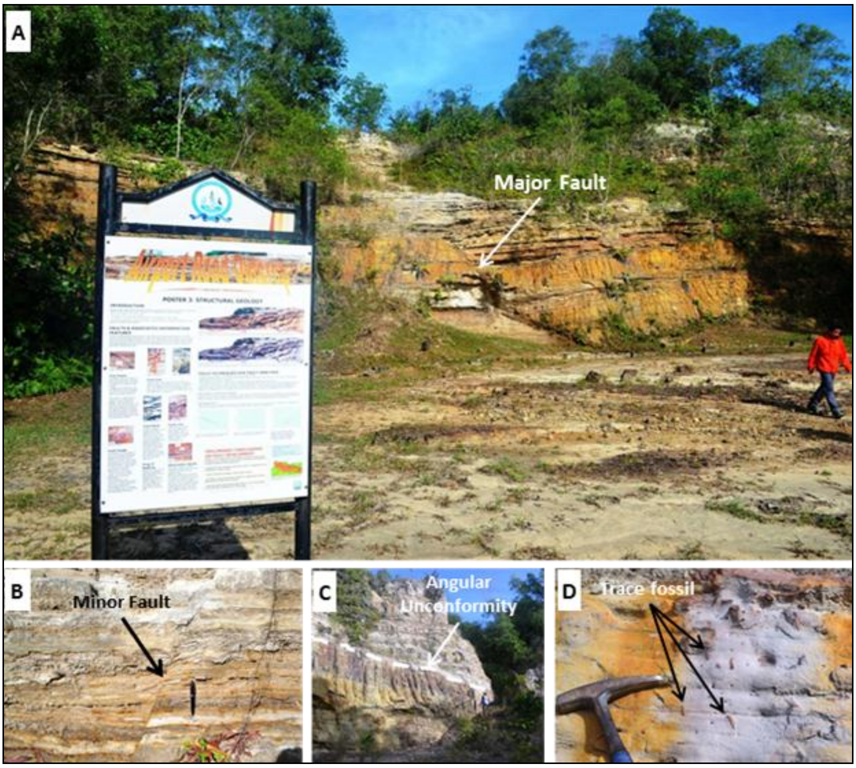

Figure 7. The Airport Road Outcrop in Miri: (A) The recent situation of the outcrop museum, (B) One example of minor fault in the interbedded sandstones, shales, and mudstones, (C) A feature of angular unconformity in the outcrop as a contact between rocks, (D) Many trace fossils, such as Ophiomorpha (in burrows) encountered within the sandstone

In addition to its importance as the reservoir rocks in the past, this outcrop exposes a world-class faults exposure which can be followed over large distances, along vertical and horizontal surfaces. This is the evidence that the area has suffered from tectonic activities. The outcrop, according to Van der Zee & Urai (2005), exposes over 450 normal faults with throws ranging from several centimeters to over 25 meters. The outcrop such as this is rare in Malaysia, where a 3-dimentional view of the faults can be observed. Some faults in the outcrop are major faults and some others are minor ones. In petroleum geology, faults are one of important structural traps of petroleum. Tongkul (2005) elaborated that the Miri Oil Field consists of a large number of fault blocks, similar to the ones exposed here. Therefore, this outcrop provides an excellent analogue to understand the subsurface geology of the Miri Field. Visitors can also observe some other geological features formed in this sedimentary rocks such as cross stratification and angular unconformity. Trace fossils, such as burrows of Ophiomorpha, can be found in some parts of the outcrop, indicating that the sedimentary rocks deposited in the shallow marine environment.

The deltaic sandstone outcrops on the Lopeng Road also provide excellent analogues of reservoir rocks in Miri area. Some fresh outcrops were exposed by hill cutting works for the construction project, allowing a good observation to visitors. The outcrops in this area show relatively horizontal layers of some sedimentary rocks such as sandstones (the most common), shales, claystones, siltstones, and mudstones (Figure 8). Some faults can be observed clearly in the outcrops. The authors have found some bivalvia fossils in one of the outcrops during the field work. The authors named these outcrops as the “Sarawak Layer Cake outcrops” since they look like the famous local snack, Sarawak layer cake. Some other new deltaic outcrops in the area are perhaps continously exposed that may provide opportunities to study the geological features, such as sedimentary rocks, sedimentary structures, geological structures, fossils and so on. These locations are also appropriate to take a measurement of strikes and dips of the sedimentary rock beds and some throws of faults.

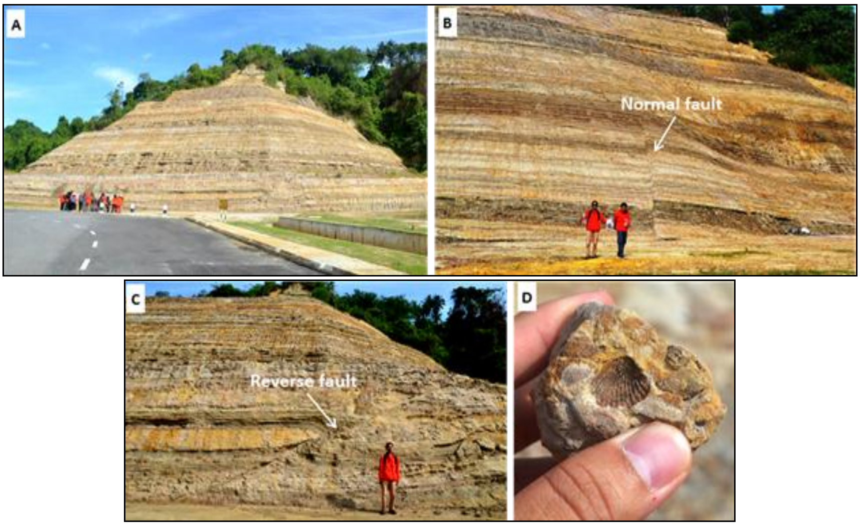

Figure 8. The deltaic sedimentary rocks on the Lopeng Road, Miri: (A) The first hill outcrop, (B) The second hill, next to the first hill, show similar rock sequence and an example of normal fault, (C) A reverse fault in the first hill outcrop, (D) A trace fossil of bivalvia from this area

Oil seepage

Seepage of petroleum, both oil and gas seeps, are natural springs where liquid and gaseous hydrocarbons leak out of the ground. Oil and gas seeps are fed by natural underground accumulations of oil and natural gas (USGS PCMSC, 2011). The seeps can occur both onshore and offshore and are composed of mixtures of crude oil, asphaltum (tar), natural gas, and water (DOC, 2013). Leythaeuser (2005) stated that petroleum seepage at the Earth’s surface is a consequence of disturbance on cap rocks such as fracturing or cracking. The natural oil/gas seep is one of hydrocarbon indications of an area. In Miri and its surrounding areas, oil has seeped naturally from underground sources to the Earth’s surface, such as oil seeps in an outcrop along Padang Kerbau road, on top of Canada Hill, in an outcrop in Lambir Hills, and in an outcrop along Miri-Bekenu coastal road (Figure 9).

Mud volcanoes

Mud volcanoes are geological features formed as a result of the emission of argillaceous material on the Earth’s surface or the sea floor. The mixture of sufficient water, gas, and mud (fine-grained sediments from subsurface formations) will produce semi-liquid material and will be forced up through long narrow openings or fissures (conduits) along the lithologic succession to produce an outflowing mass of mud on the surface (mudflow). The extruded material forms characteristic morphological features with various shapes (from positive features such as conical shape or dome and ridge to negative ones such as mud pool and mud pie) and sizes (from very large structures - up to 100 km², to small landforms - a few tens of square meters). Despite their name, they are actually not related to volcanic activity and the only characteristics that link them with magmatic volcanism are the surface morphology and the vague resemblance in the activity (Dimitrov, 2002; Kopf, 2002).

Figure 9. Some oil seeps in and around Miri: (A) An outcrop along Padang Kerbau road, (B) A ditch on top of Canada Hill, (C) An outcrop in Lambir Hills (D) An outcrop along Miri-Bekenu coastal road (Source: Wannier et al., 2011).

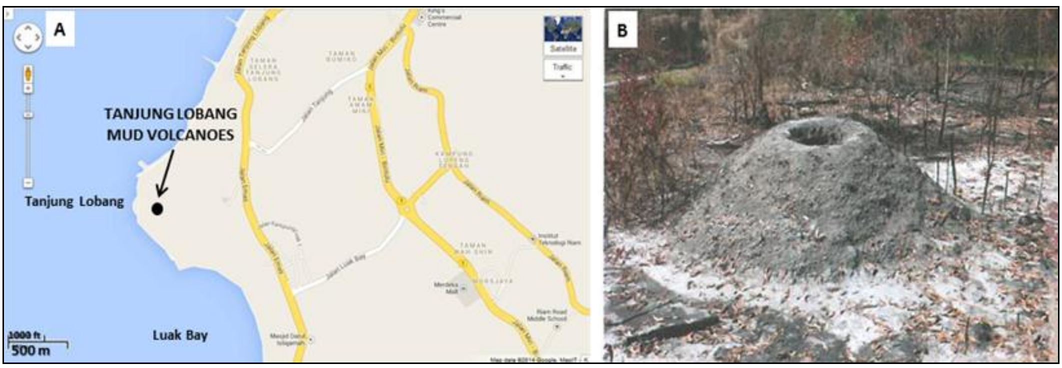

Figure 10. Inactive mud volcanoes can be observed in Tanjung Lobang area: (A) The location map of the Tanjung Lobang mud volcanoes (Source: Google Maps 2014), (B) A well-preserved remnant cone of an inactive mud volcano in the area (Source: Wannier et al., 2011)

One of the factors controlling the occurence of mud volcanoes is continuous active hydrocarbon generation and one of the main driving forces is high pore-fluid pressure provided by gases, so it can be considered that mud volcanoes can be used for predicting the presence of petroleum in the subsurface (Dimitrov, 2002). Mud volcanoes are common in many areas of Northern Sarawak, Brunei, and Sabah where Setap Shale Formation crops out in those areas (Wannier et al., 2011). Some mud volcanoes, both active and inactive, can be observed in some locations in and around Miri area. A series of inactive mud volcanoes in Tanjung Lobang (coordinates: N 04°21'32.34", E 113°57'42.89") have been reported by Wannier et al., (2011). The mud volcanoes have about 1.5 m high conical mounds, and one of them has its well-preserved crater (Figure 10). Some active mud volcanoes called Ngebol Mud Volcanoes (coordinates: N 04°04'54.8", E 113°58'30.5") have been reported among others by Tan et al. (1999) and Wannier et al., (2011). These mud volcanoes are situated within the oil palm plantation in Bukit Peninjau area. The accessibility to the location of these mud volcanoes is from Miri go through the Miri – Bintulu Road, then in Km. 44 turn left at the junction to Beluru and the Logan Bunut National Park, near the Bekenu junction.

After driving for 2.1 km, visitors will reach the car park area or the start of the trail to the mud volcanoes. It takes around 2 km or 30-45 minutes hiking in the middle of the oil palm plantation from the start of the trail to the mud volcanoes. Local people call the place "Ngebol" which means "seepage". These mud volcanoes are composed of mudstone of the Setap Shale Formation and gases. Mud volcanoes here consist of water-rich muds which create low and broad craters, reaching a maximum of one meter in height. The origin of the gases (consist usually of methane) is mostly related to hydrocarbon generation in the subsurface (Wannier et al., 2011; Figure 11).

Figure 11. Ngebol mud volcanoes in Bukit Peninjau area, near Miri: (A) The location map of the Ngebol mud volcanoes (From Google Maps 2014); (B) The aerial view of the Ngebol mud volcanoes (From Google Maps 2014); (C) Overview of Ngebol mud volcanoes, (D) Two different morphological features (an emerged cone at the forefront and a pond at the back) of the Ngebol mud volcanoes (Source: Wannier et al., 2011)

Beaches from Tusan to Tanjung Batu

The long stretch of sandy beaches with rocky cliff leading from Tusan (coordinates: N 04°07’32.1”, E 113°49’25.9”) to Tanjung Batu (coordinates: N 04°07’14.5”, E 113°49’02.9”) offers opportunities to observe many interesting geological features. These beaches (Figure 12) are located in between Kampung Beraya Laut and Kampung Terahat, around 40 km towards SW of Miri and facing the South China Sea. These beaches can be accessed from Miri city through the coastal highway towards Bekenu. The right turn from a three junction at around km 40 leads to Tusan Beach. Tusan (literally mean “at door step”) Beach provides a scenic view from atop of the cliff and Tanjung Batu Beach (also named “Rocky Isthmus”), which can be accessed only from Tusan Beach, also provides beautiful features that are best enjoyed along the coast southwestwards around 45 minutes during the low tide.

Figure 12. The location map of Tusan Beach and Tanjung Batu Beach
(Source: Google Maps 2014)

According to Felix Tongkul (2005), these beaches are composed of sedimentary sequence of the Lambir Formation, which consists of sandstone and mudstone showing interesting sedimentary structures and contains a rich assemblage of fossils such as gastropods, bivalves, and crabs. Among interesting geological features which can be observed at Tusan Beach are the sea-dipping sandstone cliff with the strike/dip of sedimentary layers is N225°E/35°, the wonderful horse head-shaped arch exposes angular unconformity between Miocene sedimentary rocks and Pleistocene terrace deposits, some sea caves scattered in the sandstone bodies, and some sedimentary structures such as cross bedding and taphony structures. Meanwhile, at Tanjung Batu Beach, a prominent sea stack and conglomerate blocks with soft sediment deformation structure are among the interesting features can be observed (Figure 13). The wave and wind erosions are the dominant processes occur in the area which continously change the coastal morphology of the area from time to time.

There is another significant and valuable feature in term of petroleum geology can be found at Tanjung Batu Beach, it is oil sands, also known as "tar sands" (Figure 14). Oil sands are sediments or sedimentary rocks composed of sand, clay minerals, water and bitumen. The oil is in the form of bitumen, a very heavy liquid or sticky black solid with a low melting temperature. Bitumen typically makes up about 5 to 15% of the deposit (OSTSEIS, 2012; Geology.com, 2014). The composition of oil sands consists of sand grains, an ‘envelope’ of water surrounding a sand grain, and a film of bitumen surrounding the water (Canadian Centre for Energy Information, 2014).

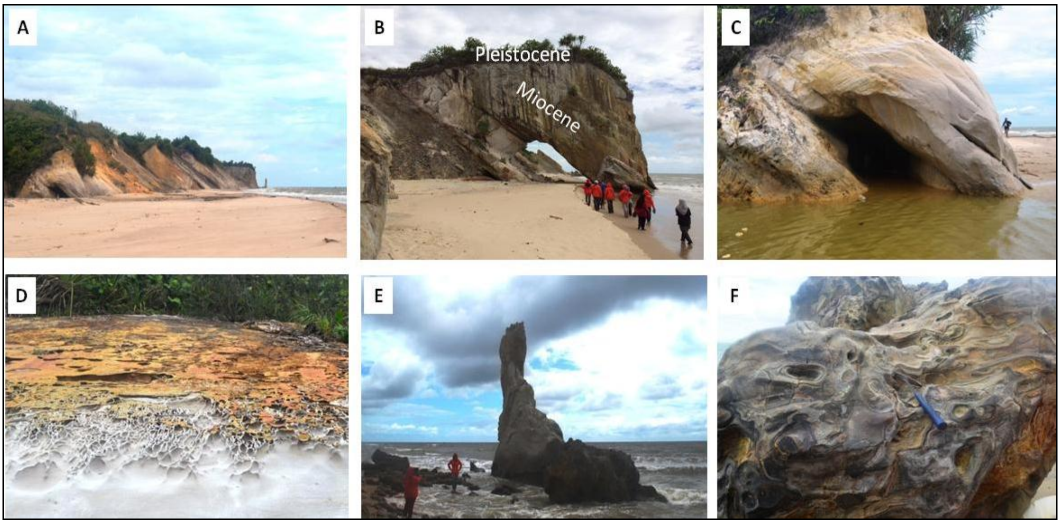

Figure 13. Tusan Beach and Tanjung Batu Beach provide so many interesting geological Features: (A) Tusan cliff, (B) A horse head-shaped arch, (C) One of sea caves at Tusan Beach, (D) Taphony or honeycomb structure in the sandstone cliff at Tusan Beach, (E) A sea stack at Tanjung Batu Beach, (F) Soft sediment deformations of a conglomerate block in the tidal environment found at Tanjung Batu Beach

Figure 14. Oil sands (also known as "tar sands") as one of petroleum treasures: (A) Some boulders of oil sands scattered at Tanjung Batu Beach, near Miri, (B) Each oil sand grain has two layers: an 'envelope' of water surrounding a grain of sand, and a film of bitumen surrounding the water (Source: Canadian Centre for Energy Information, 2014)

Niah Caves as an analogue of subsurface carbonate reservoirs

Niah Caves are parts of Niah National Park which is located around 110 km in the SW of Miri city (or around 2 hours from Miri to the park headquarter) and around 3 km from the nearest town of Batu Niah (Figure 15). The cave complex is situated on the northern part of the national park, along the Miri-Bintulu Road, near Niah River, and about 20 km inland from the sea (the South China Sea) on the north coast of Sarawak.

This world-famous Niah Caves were declared as a National Historic Monument in 1958 and gazetted as a National Park in 1974, and now has been proposed as a World Heritage Site to UNESCO.

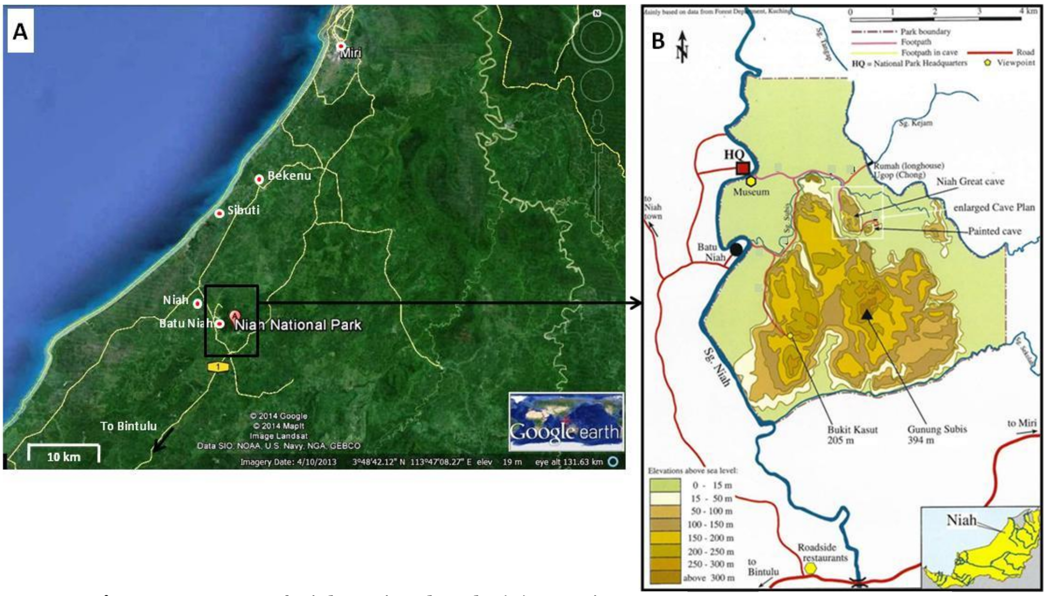

Figure 15. Maps of Niah National Park: (A) Location map (Source: Google Maps 2014), (B) Topographic map (Source: Hazebroek & Abang Kashim, 2006)

Figure 16. The road and some infrastructures and facilities have made the journey to the Niah Caves convenient to visitors: (A) An excellent road from Miri to the Niah Caves, (B) The HQ of Niah National Park, (C) The jetty of Niah River, near the park HQ, (D) The Niah Archeological Museum, (E) The plank walk, (F) One of the signboards provided in the Caves

The national park covers around 31 km² of limestone hills and lowland forest. The largest of these hills, Mount Subis (394 m above sea level) dominates the landscape (Hazebroek & Abang Kashim, 2006). The excellent road link the national park to some towns such as Batu Niah, Niah, Miri, and Bintulu. Besides that, some supporting infrastructures and facilities have been built to make visitors convenient to explore the caves, such as the park HQ, jetty of Niah River which links the HQ and the caves, Niah Archeological Museum as the place to preserve archeological things from the area, plank walks and signboards which provide an easy and enjoyable journey to visitors (Figure 16). All these infrastructures and facilities enable visitors to arrange their visit to the Niah Caves as a one day trip. The giant cave complex consists of the largest cave with the name of Niah Great Cave and several smaller caves including the Traders Cave and the popular Painted Cave. Geologically, Niah National Park consists of the limestone hills and caves which are part of the Subis Limestone (named after the highest hill) which covers an area of about 16 km^2. Mount Subis is mainly built of massive, cliff-forming limestone, and surrounded by the lowland consists mainly of marls with occasional limestone fragments. All these limestone and marls belong to the Tanggap Formation. Some parts in the NE dan SW of the national park area consist of sandstone of the Nyalau Formation which forms more gentle slopes and underlies the limestone. A major NE-SW trending fault cuts right through Mount Subis (Figure 17). Inside the caves, the floor of the caves is covered by clay and guano (bird and bat droppings) and scattered limestone boulders (Hazebroek & Abang Kashim, 2006).

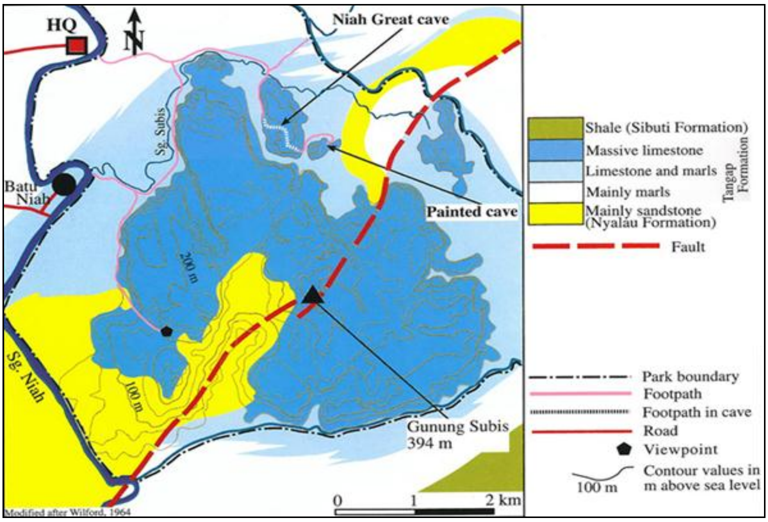

Figure 17. Geology of Niah National Park (Source: Hazebroek & Abang Kashim, 2006)

Niah Caves are also an important archeological site in Sarawak and Malaysia. Archaeologists have discovered the evidence of man's existence in Borneo dating as far back as 40,000 years ago, such as the skull of a young Homo Sapien, some tools made of stone, bone, and iron, as well as cave drawings. Anthropologists established that the Niahian lived in the caves from 40,000 BC right up to 1400 AD (Geographia, 2006).

From the perspective of petroleum geology, the Niah Caves system can be used as an analog for carbonate reservoirs. Feazel (2010) explained that karst processes, hydrology, dimensions and architecture are useful in understanding karsted rocks that serve as reservoirs for oil and natural gas. Karst processes ranging from surface weathering to deep burial dissolution have affected numerous karst intervals that host petroleum accumulations. In the case of Niah Caves, the Subis limestone and these caves (Figure 18) can also be “seen” as a carbonate reservoir and are useful in understanding the characteristics and properties of this type of reservoir. For example, the cave passages can be used to infer the porosity and connectivity of carbonate reservoirs. The Great Cave consists of more than 3 km of passages where the entrances (mouths) are on the west, east, and south sides of the hill. Small stalactites are common within the caves, some of which have grown into pillars/colomns. Holes in the roof of the caves form connections to the surface. Where these passages join, they form large chambers up to 60 m high and 90 m wide. Other passages are high and narrow. They are connected laterally by tubular passages (Hazebroek & Abang Kashim, 2006).

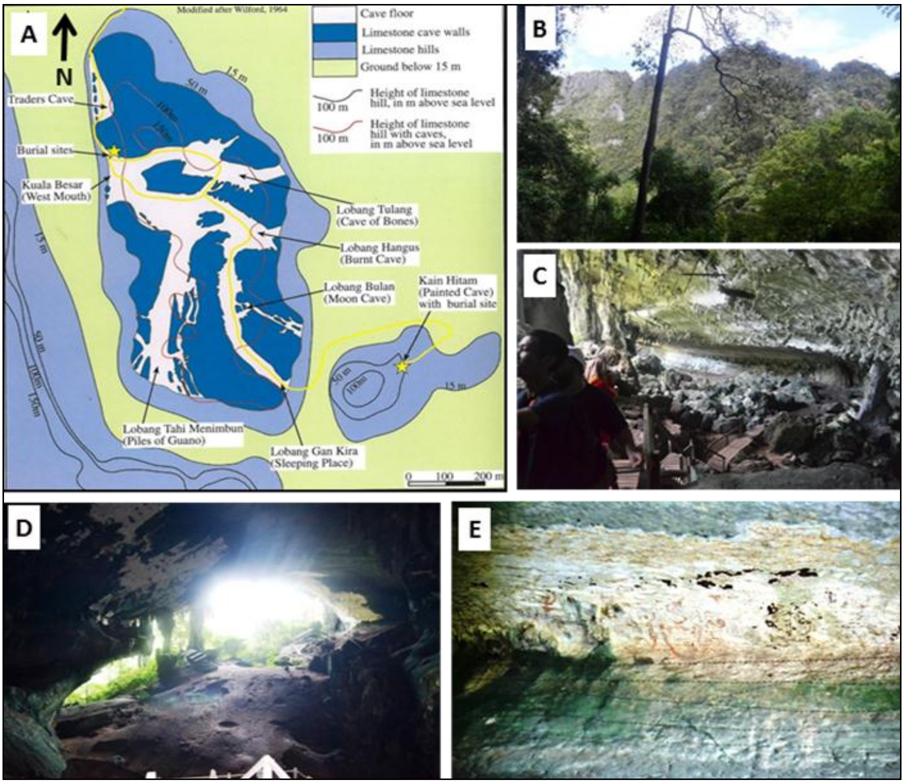

Figure 18. The modern cave systems (such as the Niah Caves) can be used as an analog to study carbonate reservoir rocks: (A) Plan view of Niah Great Cave (Source: Hazebroek & Abang Kashim, 2006), (B) The massive, cliff-forming Subis limestone that dominates the Niah National Park, (C) The overhang of Traders Cave, (D) The main entrance (called the West Mouth, around 49 m above sea level) and the largest passage of the Great Cave with its arc-shaped ceilings, (E) The wall of the Painted Cave

CONCLUDING REMARKS

This study shows that Miri and its surrounding areas consist of some important petroleum geology-related sites, both geological/natural and man-made features, which are potentials for geotourism resources. Among those sites are the Canada Hill, the Grand Old Lady (the Well No.1) and Petroleum Museum on top of the hill, the deltaic sandstone outcrops of Miri Formation (such as the famous Airport Road outcrop and other deltaic outcrops), oil seepage and mud volcanoes in some locations in and around Miri, oil ("tar") sands in Tanjung Batu Beach, and Niah Caves. All these features and sites should be conserved and developed properly, mainly for scientific and educational purposes as well as for geotourism development of the area.

Acknowledgement

The authors wished to thank Faculty of Earth Science, Universiti Malaysia Kelantan (UMK) for giving us the fund to organize a trip to Miri and run this small project. We also appreciate staff of Petroleum Museum and Sarawak Shell Berhad for their warmest welcome during our visit in May 2014.

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Submitted:	Revised:	Accepted and published online
05.10.2014	26.02.2016	29.02.2016