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Cover Photograph:
The contact of Sawahlunto Formation (dark color at the bottom part) and Sawah Tambang Formation (bright color) outcrop near Sawahlunto city – West Sumatera. Taken in June 2012.
Photo courtesy of Kirandra Ferari and Peri Raudatul Akmal from IAGI Riau.
Berita Sedimentologi

A sedimentological Journal of the Indonesia Sedimentologists Forum (FOSI), a commission of the Indonesian Association of Geologist (IAGI)

From the Editor

Welcome to Berita Sedimentologi number 27!

We’re very pleased to deliver another volume of Berita Sedimentologi to you. In this 27th edition of Berita Sedimentologi, we received 5 articles, including 2 articles from students to show our commitment to engage their interest in publishing their work on sedimentology/stratigraphy.

Berita Sedimentologi No. 27 focuses on Sumatra island however only three articles will discuss about Sumatra, while the rest of them are on other areas. The articles on Sumatra include a short communication on late synrift turbidite systems in the North Sumatra Basin written by Lawrence (Trey) Meckel, a field trip report to Central Sumatra prepared by Andrew Carnell and a student article on fractured basement in the Malacca Strait by Ignatius Primadi.

Lee Chai Peng submitted an article on stratigraphy of the Langkawi Island, Malaysia; and a group of students from Diponegoro University in Central Java wrote a short article on depositional environment analysis of Kali Banyumeneng (Demak, Central Java).

We would like to remind you of our plan for near future publication themes as follow:
- BS#28 Borneo: to be published in November 2013
- BS#29 SE Asia Biostratigraphy to be published in early 2014

Invitations have been sent out to potential contributors to seek articles for both volumes. We hope to get enough responses for future publications and in the meantime, we hope you will benefit from the current edition of Berita Sedimentologi. See you again in November.

Warm Regards,

Minarwan
Deputy Chief Editor

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About FOSI

The forum was founded in 1995 as the Indonesian Sedimentologists Forum (FOSI). This organization is a communication and discussion forum for geologists, especially for those dealing with sedimentology and sedimentary geology in Indonesia.

The forum was accepted as the sedimentological commission of the Indonesian Association of Geologists (IAGI) in 1996. About 300 members were registered in 1999, including industrial and academic fellows, as well as students.

FOSI has close international relations with the Society of Sedimentary Geology (SEPM) and the International Association of Sedimentologists (IAS).

Fellowship is open to those holding a recognized degree in geology or a cognate subject and non-graduates who have at least two years relevant experience.

FOSI has organized 2 international conferences in 1999 and 2001, attended by more than 150 international participants.

Most of FOSI administrative work will be handled by the editorial team. IAGI office in Jakarta will help if necessary.

The official website of FOSI is:
http://www.iagi.or.id/fosi/

FOSI Membership

Any person who has a background in geoscience and/or is engaged in the practising or teaching of geoscience or its related business may apply for general membership. As the organization has just been restarted, we use LinkedIn (www.linkedin.com) as the main data base platform. We realize that it is not the ideal solution, and we may look for other alternative in the near future. Having said that, for the current situation, LinkedIn is fit for purpose. International members and students are welcome to join the organization.
Review of the Palaeozoic Stratigraphy of the Langkawi Islands, Malaysia

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**INTRODUCTION**

The Langkawi group of 99 islands off the northwest coast of Malaysian Peninsula is located some 30 km off the coast of Perlis and 112 km north of Penang. These islands are a paradise for geologists, including some of the best and most interesting exposures of Palaeozoic sedimentary rocks in Malaysia, ranging in age from Cambrian to Permian. These consist of both clastics and carbonates, deposited within a range of depositional and palaeoclimatic conditions ranging from shallow marine shoreface to turbidites with dropstones. In addition, these sedimentary rocks had been intruded by younger Mesozoic granites with considerable contact metamorphic effects.

Since the initial publication of the Geological Map of Langkawi and the subsequent Geology and Mineral Resources Memoir 17 on the States of Perlis, North Kedah and the Langkawi Islands, both by Jones (1966, 1981) many more recent studies had been carried out. These studies were particularly facilitated by the creation of new outcrops due to numerous recent development projects on the islands. A helpful compilation of published and unpublished geological researches on Langkawi was compiled by Sarman et al. (1997).

The spectacular geological heritage of the islands heralded the formation of the Langkawi Geoforestpark by the Kedah State Government, Malaysia in May 2006 to preserve and display its unique geological features. The Geoforestpark was endorsed by the United Nations Educational, Scientific and Cultural Organization (UNESCO) under the Global Network of National Geoparks in June 2007 (Leman et al., 2007).

**REGIONAL GEOLOGICAL SETTING**

Langkawi is located within the Northwestern Domain of the Western Belt of Peninsular Malaysia (Figure 1) which is an integral part of Sundaland, the SE Asian extension of the Eurasian plate.

**Figure 1.** Location map of Langkawi Islands. The three belts and northwestern domain within the Western Belt are after Lee (2009). Sumatra map is after Darman & Sidi (2000).
The Paleozoic sedimentary rocks of Langkawi are mostly shallow-marine shelf type deposits that extend within a broad linear belt from South China, through Burma, Thailand, and northwest Peninsular Malaysia into northern Sumatra. These sediments form part of the Sibumasu Block which broke away from northwestern Australia at the northern edge of Gondwanaland, to subsequently collide with the Indochina or East Malaya block along the Bentong-Raub Suture during the Triassic (Metcalfe, 2000; Hutchison, 2009a). The above-mentioned Northwestern Domain is part of the Patani Metamorphic Terrane related to this plate tectonic suturing episode.

Cenozoic uplift of the Langkawi chain of islands is related to the peripheral effects of later Neogene collision of India with Tibet creating the Himalayas as well extrusion of Sundaland to the southeast (Tapponier et al., 1982). In addition, the Langkawi islands, being geographically located on the northern cratonic margin of the North Sumatra Basin, have been affected by Neogene block faulting caused by back arc extension associated with the continuous northwards push of the Australian Plate under the Eurasian Plate (Raj et al., 2009).

### STRATIGRAPHY OF LANGKAWI

The Palaeozoic sedimentary rocks in Langkawi are traditionally subdivided into four formations (Jones, 1981), although newer more detailed stratigraphic subdivisions have been proposed (Cocks et al. 2004; Meor and Lee, 2004; Lee, 2009). These units are, from the oldest to the youngest, the Machinchang, Setul, Singa and Chuping Formations. Their geographical distribution and stratigraphic relationships are given in Figures 2, 3 and Figure 4, respectively. They are mostly shallow marine shelf type deposits and are discussed as follows:

**Figure 2.** Revised stratigraphy of Palaeozoic rocks up to the Singa Formation in the Northwestern Zone of Peninsular Malaysia (after Lee, 2009).
1. Machinchang Formation

The Machinchang Formation type locality is derived from the conspicuous long serrated quartzite ridge of five peaks aptly called Gunung Machinchang or Mat Chinchang meaning "chopped-up mountain" (Figures 5a & 5b). This formation is composed of a thick succession of predominantly arenaceous rocks with minor interbeds of conglomerates, phyllitic slates and tuffs exposed in the northwestern corner of Langkawi. It has been divided into three members (Figure 6) according to Lee (2006) with a coarser sandy middle member sandwiched between two finer grained members. The overall depositional environment is that of a high-destructive, wave-dominated delta which had built over an offshore shelf deposit to produce a series of barrier-beach sands cut by small channels (Lee, 2009).

Figure 3. Geological map of Langkawi Islands showing distribution of the various rock formations in the islands (after Leman et al., 2007). Common stops on field trip are numbered in circles.
In the Machinchang area these rocks spectacularly outcrop as an asymmetrical anticline with a relatively undisturbed western limb that dips and plunge into the waters of the Straits of Malacca (Figure 5b). Up section occurs a gentler more dome-like eastern limb that probably had been uplifted by underlying Mesozoic granite (Lee, 1983). The base of the formation is not exposed and the oldest part of the formation is the pelitic rocks exposed in the core of the Machinchang Anticline at Teluk Datoi. The top of the formation has several thin calcareous horizons before passing conformably up into the succeeding Setul Formation limestone near Teluk Sabong.

**Figure 4.** Stratigraphy and major events in geological history of Langkawi islands (after Leman et al., 2007).

**Figure 5.** a) “Chopped up” Machinchang Range view from the south; b) Machinchang Formation deltaic sandstone beds in western limb of anticline dipping steeply into Malacca Strait.
The table and diagram provide information on the stratigraphy of the Machinchang Formation. The lithology and description of each unit are detailed as follows:

**Figure 6. Stratigraphy of the Machinchang Formation (after Lee, 2006).**
Interesting trace fossils including *Dictyodora* (Lee, 1980) and sedimentary structures such as various types of cross-beddings, convolute bedding and load casts can be seen in the upper parts of the formation at Pasir Tengkorak and Pulau Jemurok. Palaeocurrent studies on the abundant cross-beddings found in the formation gave a predominantly westward downcurrent direction.

The Machinchang Formation is poorly fossiliferous and only poorly preserved fragments of trilobites and brachiopods had been found at Tg. Buta and Pulau Jemurok. Better preserved fossilized saukid trilobites and orthid brachiopods are found on Tarutao Island just 5 km north of Langkawi in Thailand which give a Late Cambrian to Early Ordovician age to the uppermost part of the Machinchang Formation. This is confirmed by fission track studies on zircon crystals which give an age of 555±37 Ma.

Acid volcanics or tuffs also occur as thin, fine grained, pale green layers in the Machinchang Formation indicative of acid volcanism during Cambrian times.

2. **Setul Formation**

The Setul Formation ranges in age from Early Ordovician to Early Devonian. It is divisible into a Lower Setul Formation of Ordovician age, occurring below the Lower Detrital Band on Pulau Langgun and a Silurian to Devonian Upper Setul Formation above this band (Figure 4). The top of the formation is represented by the Upper Detrital Band, a largely arenaceous unit with minor argillaceous beds at Teluk Mempelam on Pulau Langgun. The formation has been estimated to be about 1500 m thick and was raised to group status in Cocks et al. (2005) and Lee (2009).

The Setul Formation is made up of predominantly dark coloured shelfal limestone with minor black detrital bands. It is largely metamorphosed on the main island but good fossiliferous outcrops of the limestone are present in the vicinity of Pulau Langgun. The impure limestone contains a rich fauna of fossils such as gastropods, bivalves, nautiloids, brachiopods, trilobites, crinoids and stromatolites while the hardened black mudstones have preserved graptolites, tentaculitids and trilobites.

The unusual scyphocrinoid, probably *Camarocrinus* (Figure 7), with its calcareous floating lobolith has been discovered (Lee, 2005) from the top part of the Upper Setul limestone at Teluk Mempelam on Pulau Langgun. It is restricted in age to the uppermost Pridolian-lowermost Lochkovian (Late Silurian to Early Devonian) and enables correlation with similar limestones in Myanmar (Ayeko Aung, pers comm. 2010). Microfossils such as conodonts and ostracods are also found in these limestones.

3. **Rebanggun Beds**

The quartzitic sandstones and red to grey mudstones known as the Rebanggun Beds outcrop on Pulau Rebak Besar and Pulau Rebak Kecil and have been grouped together with similar beds found above the Setul Formation at Pulau Langgun.

*Figure 7. Upper Setul limestone bed with scyphocrinoid loboliths at Teluk Mempelam, Pulau Langgun, northeast Langkawi.*
Correlation with better exposed sequences in Perlis has placed the Langgun Redbeds higher up instead of at the base of the transitional unit (Lee, 2009) to the Singa / Kubang Pasu Formations. Fossils in this unit are sparse and consist of small ambocoelid brachiopods, Posidonomya (Posidonia) bivalves and the trilobite Macrobole kedahensis. The age of the unit is probably Early Carboniferous

4. Singa Formation

The Singa Formation is best exposed in the southwestern part of Langkawi. The basal contact with the Rebanggun Beds is unexposed and the top is gradational into the overlying Chuping Formation limestone that is exposed on Pulau Singa Kecil.

The age of the formation is probably Carboniferous to Early Permian. The Singa Formation, named after Pulau Singa Besar, is a clastic unit typified by crudely laminated, dark grey, poorly sorted mudstones with scattered dropstone horizons. The dropstones range in size from granules to boulders (Figure 8) and are mainly composed of sandstone with subordinate limestone, vein quartz, granitic, volcanic and metamorphic rocks.

They have been interpreted as glacial marine dropstones derived from peri-Gondwana margin ice sheets during the Carboniferous (Stauffer & Mantajit, 1981; Stauffer & Lee, 1986). Fossils are only common in its uppermost section but burrows and soft sediment deformation structures can be found in some parts. Long paired vertical burrows exceeding a meter in length are found on Pulau Tepor. The brachiopods found in the uppermost part of the formation associated with dropstone horizons at Kilim, Batu Asah and Pulau Singa Besar are “cool-water” forms of Permian (Viséan) based on Macrobole and its stratigraphic position above Late Touraisian chert beds. These fossiliferous mudstones and associated sandstones that are pebbly in places were deposited in a quiet prodelta environment with occasional turbiditic input. These redbeds are quite widespread and correlatable with the Khao Chunong Formation in south Thailand. (Sakmarian) age (Waterhouse,1982; Leman, 2003). Other associated fossils are bryozoa, bivalves, gastropods, corals and crinoid stems. Sandstone beds are few and often calcareous.

The formation can be correlated with similar glacial marine diamictites found in the Mergui, Martaban and Lebyin Groups of Myanmar, the Kaeng Krachan Formation of the Phuket Group in Thailand and the Bohorok Formation of Sumatra.

5. Chuping Limestone

The Chuping Limestone is a unit of thickly bedded to massive, light coloured limestone (Figure 9) that sits conformably above the Singa Formation in the southeastern part of the island. It can be easily distinguished from the more clayey and darker coloured Setul limestone.

The Chuping limestone is fossiliferous in its basal part with fusulines, brachiopods, bivalves, gastropods, corals, bryozoans and algae ranging from a late Early Permian or early Middle Permian age in Langkawi to the Triassic on the mainland (Metcalfe, 1990). Chert nodules are common at its base in Pulau Singa Besar. The once famous Langkawi marble is a white saccharoidal ornamental stone quarried from metamorphosed equivalents of this limestone in southeastern Langkawi and Pulau Dayang Bunting.

Figure 8. Glacial marine dropstones in pebbly mudstone horizon in Singa Formation at Pulau Ular.
Mesozoic Igneous Rocks

Two granitic bodies are found in the islands. The Raya and Tuba granites cover some 113 km² of the islands. The huge Gunung Raya massif which rises to 878 m forms the highest part of the island. It is Late Cretaceous in age while the smaller pluton in Pulau Tuba is Late Triassic in age. The granites are petrographically similar and hard to distinguish in the field. Both are porphyritic biotite granites with tourmaline clots and veins (Figure 10).

Figure 9. White coloured marble of Chuping Formation behind former Kedah Marble factory near Kisap.

Figure 10. Tourmaline-quartz vein in Langkawi granite block.
Large K-feldspar phenocrysts and spherical quartz phenocrysts are common. Alignment of the large K-feldspar crystals is common at the margins of the plutons. The Raya Granite appears to be the most southerly body of a belt of Late Cretaceous granite extending from west Thailand.

Metamorphic Rocks

Langkawi occurs within the Patani Metamorphic Terrane which trends northwest from mainland Kedah (Khoo, 1984). Rocks older than mid-Permian within this terrane have suffered severe deformation and low grade regional metamorphism related to the collision of the Sibumasu micro-plate with Indochina. Rocks of the Machinchang, Setul and the Singa Formations have developed at least one set of low angle cleavages.

These rocks occur as slates, phyllites, quartzites and fine grained marbles where unaffected by later contact metamorphism while rocks adjacent to the granites have recrystallized to mica schists, coarse grained marbles and tough metaquartzites. Small bodies of skarn have developed at the contacts between the igneous intrusions and some of the limestones.

CONCLUSIONS

Langkawi plays an important role in the palaeogeographic reconstruction of the northwestern part of Peninsular Malaya.

The discovery of Lower Permian (Sakmarian) cool-water shelly fauna particularly brachiopods in the Singa Formation (Waterhouse, 1982; Leman, 2003; Shi et al., 1997) in addition to glacial marine dropstones (Stauffer & Mantajit, 1981; Stauffer & Lee, 1986) has enabled correlation with similar deposits in the Canning Basin of Australia (Hutchison, 2009b). This establishes the connection of Langkawi to Gondwana in pre-Late Permian times, when it formed part of the Sibumasu microcontinent.

Sibumasu subsequently drifted north into lower palaeo-latitudes and eventually collided with the warmer climate provinces of the Indochina Block of Cathaysia, along the Bentong-Raub Suture of Peninsular Malaysia during the Late Triassic.

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Short communication
Late Syn-Rift Turbidite Systems in the North Sumatra Basin

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The North Sumatra Basin (NSB, Figure 1) in Indonesia is one of the most prolific petroleum provinces in SE Asia. It has been affected by rifting, transtensional and transpressional shear, and compression from the Paleogene to present day. This complex tectonic history has created numerous opportunities for petroleum exploration, including an inverted deepwater turbidite play (Figures 2 and 3) that has been relatively underexplored to date.

During the late syn-rift stage of basin evolution (Late Oligocene-Early Miocene), N-S to NE-SW oriented half-grabens in the central and northern part of the NSB (Figure 3) were subjected to rapid flooding, as a result of the complimentary effects of tectonic subsidence and a rise in eustatic sea level. Water depths reached several hundred meters (bathyal paleobathymetries), and slope and basin-floor turbidite systems of the Bampo Formation (Figure 2) filled the newly-created accommodation space. Time-equivalent basement highs are characterized by unconformities or condensed, shallow marine deposits.

Intra-formational, deep marine Bampo shales act as competent seals for individual turbidite sands (Figure 2). The shale-prone stratigraphy of the stratigraphically younger Baong Formation acts as a regional seal, across which overpressures tend to increase with depth (Figure 2).

Figure 1. Location map of study area (red box) in southern part of North Sumatra Basin relative to historical well database and existing oil (green) and gas (red) discoveries. Despite significant success in the onshore and on the shelf, fewer than 40 wells have been drilled in water depths greater than 100 m. Inset, upper right shows ultimate recoverable reserves (URR) for the 13 largest basins in SE Asia. Bubble size is scaled to UR. More than 6 billion barrels of oil equivalent have been discovered in the NSB. Inset, lower left, shows the creaming curve for the NSB. Note that exploration activity has been negligible in the past decade.
During the late Miocene to Quaternary, dextral transpression on NW-SE oriented faults and N-S oriented compression formed a series of inverted structures, with potential hydrocarbon traps in 4-way dip-closures at Parapat and Bampo levels (Figure 3). These traps have not been tested in the Indonesian portion of the NSB, but contain hydrocarbons in the Mergui Basin, the northern equivalent of the NSB, offshore Thailand.

Bampo marine shales are the most probable source rocks (Figure 2). The Bampo source rock has been typed to the gas-condensate at the supergiant Arun gas-condensate field.
It is a very lean source rock, with typical TOC values less than 1%, but has a demonstrated capacity to charge multi-TCF gas fields across the NSB, so must be considered to be an ultra-prolific - if not particularly spectacular - source rock. Older, syn-rift lacustrine shales, which could be liquid-prone, may also act as potential source rocks (Figure 2). Their presence across the basin is much more speculative, though, and they have not been definitively typed to any hydrocarbon accumulations. Migration is postulated to occur from deep grabens, which thermal models show to be in oil to post-mature temperature windows, up carrier beds and faults into closures.

This wildcat inversion play has not been explored previously in the NSB because it only occurs in the offshore part of the basin, where good-quality 3D seismic data, only recently acquired, are necessary to adequately characterize prospects. The play has high volumetric potential, and most aspects of the petroleum system have been proven previously. The play concept is also relatively under-explored elsewhere in southeast Asia, and opens possibilities in other basins in the region (Figure 4).
A Field Trip to the Syn-Rift Petroleum System of Central Sumatera

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In September 2012, a field trip was run by the authors above into the Ombilin Basin of West Sumatra province to examine outcrop analogs of the syn-rift petroleum system of Central Sumatra (Figure 1). This was organized by SEAPEX and AAPG as part of the AAPG International Conference held in Singapore. The field trip started and finished in Padang but was conducted in the Barisan mountains amidst the stunning scenery of West Sumatra.

Rift basin evolution is a key component of the petroleum systems of many Southeast Asian basins (e.g. South Sumatra Basin, Sunda Basin). Syn-rift lacustrine mudstones are prolific oil prone source rocks and syn-rift and early post-rift clastics sediments can provide excellent reservoir intervals. Rift petroleum systems are, however, geologically complex and hydrocarbon exploration within them requires a greater knowledge of the structures and sedimentological evolution of the basin than is often the case elsewhere. Local factors such as provenance and rift related tectonic activity can have a significant impact on the quality, quantity and distribution of source, reservoir and seal.

The field trip was conducted over four days with each day concentrating on a separate aspect of the petroleum system as follows:

Day 1  Basement and Regional Geology (SYN-RIFT)
Day 2  Source Rock (SYN-RIFT)
Day 3  Reservoirs (EARLY POST-RIFT)
Day 4  Syn-rift Reservoirs (SYN-RIFT)

**DAY 1 - BASEMENT AND REGIONAL GEOLOGY**

The aim of the field trip stops on the first day was to study the basement geology and to set the regional setting for the remainder of the field trip. Complex structural aspects were addressed, with reference to the problems associated with deciphering Oligocene rift related structures subsequently modified by strike slip deformation and the Plio-Pleistocene Barisan mountain uplift.

Basement in the area is varied with metamorphic, igneous and sedimentary lithologies all exposed. Basement sediments are both clastic and carbonate in nature and range in age from Lower Carboniferous to Triassic. Sediments are widely metamorphosed. The igneous component to the basement is largely of an intrusive nature with granites dominant. Radiometric dating on a variety of exposures gives late Permian to early Miocene ages with most basement igneous activity occurring in the Mesozoic.

**Figure 1.** West Sumatra, showing location of principle outcrops visited. The Karindo mine is in the highly fragmented Kiliran Sub-basin to the east. The Harau Canyon is on the north eastern margin of the Payakumbuh Basin.
Unfortunately it was not practical to visit all the basement lithologies present in the area, although a representative selection were examined. These studied outcrops give a good indication of how differing types of basement have a variable influence on topography, tectonism, sediment supply and water chemistry.

**DAY 2 – SOURCE ROCK**

The second day of the field trip was spent at the Karbindo Coal Mine, an open cast coal mine in which the Eocene Brown Shale is very well exposed (Figure 2). This is a remarkable exposure since it is one of the few places around the world where by walking up through the mine it is possible to walk up through the evolution of a syn-rift lacustrine system.

The lowest exposures in the mine are a dark grey palaeosol in terrigenous mudstone (Figure 2). This palaeosol is at least 25m thick (the base is not exposed) and represents slow sediment accumulation and subsidence. Any introduced sediment was fully reworked by pedogenetic processes so that no primary sedimentary structures remain. The palaeosol is overlain by a coal seam that varies in thickness from 5m to 18m along strike. At its base the coal is black hard and vitreous and represents peat accumulation in a slowly subsiding swamp. Towards the top of the coal are interbeds of dark brown algal rich coal that were deposited in standing water. Laterally these brown coals pass into agal-rich limestones which represent lacustrine margin carbonate accumulation. This upper part of the coal seam reflects continuing subsidence but at a rate where ephemeral lakes were able to develop. Coals show TOC and HI values of 36.71% - 71.77% and 237 - 350 respectively and are generally mostly gas prone source rocks containing higher-plant material.

The coal seam is capped by a dark brown, highly organic rich (TOC 16.3% and HI 582), undercompacted shale of irregular thickness which is an excellent quality oil prone source rock with algal organic matter predominant. This is interpreted to be the deposit of a shallow, algal rich lake and probably represents the very first development of continuous lacustrine conditions.

Overlying the carbonaceous shale are ~100m of Brown Shale facies. In the Karbindo Coal mine the Brown Shale is broadly divisible into three intervals, namely: a lower (approximately 40m thick) highly fissile paper-laminated shale, a middle (approximately 15m thick) gastropod-rich red weathering shale and an upper (approximately 50m thick) weakly laminated highly bioturbated shale. At its base the brown shale is dark brown, finely laminated and fissile. The lowermost portion is strongly calcite replaced. Thin sharp–based flood-related sandstones are locally developed and become more frequent and thicker upwards. High TOC (3.16%-8.91%) and HI (442-717) indicate an excellent quality oil prone source rock dominated by algal organic matter. Palynology reveals a

*Botryococcus* spp. rich assemblage. Deposition of the lower Brown Shale interval was in a shallow lake with a strongly stratified water column.

The middle of the studied succession comprises beds of *Goniobasis*-like and *Viviparus*-like reworked gastropods. This interval weathered red and shows a slight reduction in organic content (TOC 2.58% - 5.94%) and source quality (HI 424-547). Palynological data indicate a change in algal forms present with abundant *Pediastrum* spp recorded. This middle section of the Brown Shale is interpreted to represent an overall shallowing to a lacustrine margin setting where gasprone accumulations mark concentration by wave action.

![Figure 2. The Karbindo Coal Mine. Palaeosols in the foreground are overlain by coal, which in turn is overlain by a very thick section of lacustrine Brown Shale. Note the light coloured limestone](image-url)
The water column was strongly stratified but sufficiently oxygenated to allow bioturbation to occur. Overall deposition of the Brown Shale sediments at Karbindo is interpreted to have taken place in relatively shallow water where subtle variations in the hydrological regime have resulted in great differences in the rock record.

**Figure 3.** Allied Indo Coal Mine (Parambahan-Rasau Members, Sawahlunto Formation). Fluvialite sands are laterally discontinuous and separated by thick well developed palaeosols.

**Figure 4.** Sawahtambang Gorge (Sugar Member, Sawahtambang Formation). Sands are very well developed and show excellent lateral and vertical continuity.

**DAYS 3 AND 4 – RESERVOIRS**

The third and fourth days of the field trip concentrated on sandstone reservoirs in the syn- and post-rift sequence and how their reservoir architecture is affected by local tectonic and provenance factors. In the Central Sumatra area, as with other syn-rift sections from Southeast Asia, there is considerable variation in sandstone thickness, lateral development and quality. Such sandstones are exposed in the Ombilin Basin and its environs where, unusually for Southeast Asia, there are numerous excellent quality exposures in river beds, cliffs, road cuts and coal mines (Figures 3 and 4). It is in the last mentioned that much of the third day is spent since in these mines exposures are extensive and allow for:

- an appreciation of fluvial sandstone reservoir architecture, from isolated sand bodies surrounded by mudstones, to vertically and laterally stacked sandstone showing good three dimensional interconnection,
- Allow for an interpretation of the evolution of fluvial systems such that conditions may become suitable for sandstone aggradation in vertical and lateral sense within the same overall sequence.

Although the greater part of the outcrops are fluvial in nature and can be regarded as analogous to producing reservoirs elsewhere in Indonesia, turbidite and alluvial fan sediments were also examined. In the magnificent Harau canyon it is possible to cross over from basement to alluvial fan sediments and to walk up the alluvial fan observing how the sediments evolve with time.
Student article
Economic vs Fractured Basement: A Case Study from North Sumatra Basin

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ABSTRACT

North Sumatra basin developed during the Early Tertiary (Eocene-Oligocene) as a result of an oblique subduction of the Indian Oceanic Plate underneath the Sundaland continental block. The basin is comprised of Tertiary to Recent sediments that were deposited over Pre-Tertiary basement. Typically, in many places basement consists of complex igneous and metamorphic rocks, but it is different in the North Sumatra basin. Underneath this basin, there are carbonates (dolomites or limestones) and sandstones including the Eocene Tampur Formation that have been called economic basement. Economic basement refers to rocks that have no economic prospectivity whilst the formation is comprised of the sedimentary deposits. The term economic basement in the North Sumatra Basin should be reconsidered because some data shows porosity development in pores and fractures, therefore making them potential reservoir that can receive hydrocarbon charge from proven petroleum system in the basin.

Keywords: Economic Basement, Fractured Basement, North Sumatra Basin

INTRODUCTION

Basement and crystalline basement are defined as the rocks underneath a sedimentary basin or those covered by sedimentary rocks. Nowadays, they are not merely the rocks which accommodate the sedimentary basins but also play a significant role as hydrocarbon reservoirs in several countries including Indonesia. For example, in the Beruk Northeast Field, Central Sumatra, which has produced about 2 million barrels of oil and in South Sumatra, where several gas fields are producing from the pre-Tertiary basement, collectively have estimated reserves of about 5 TCF (Koning, 2007). Those basements are called fractured basement because they have fractures through which hydrocarbons flow. Another terminology for describing basement is by using the term economic basement. An economic basement is defined as non-petroleum prospective sedimentary rocks that underlie a sedimentary basin.

North Sumatra Basin is one of several prolific basins in Sumatra, Indonesia. The basin was formed during Early Tertiary (Eocene-Oligocene) as a result of an oblique subduction. The research area is located in Malacca Strait, approximately 150km to the NNW of Medan, the capital city of North Sumatra Province (Figure 1). The pre-Tertiary basement at this location was categorized as economic basement (Beicip, 1977 in Darman and Sidi, 2000). Darman and Sidi (2000) described the basement as being composed of sandstones, limestones, or dolomites which are dense and fractured, without any metamorphic alteration. They are supposed to be less dense than igneous or metamorphic basement, but they are difficult to be traced and identified. The fact that the basement is fractured and possibly connected to a proven petroleum system means that they can be prospective for hydrocarbon exploration. The main objective of this study is to reconsider the basement of North Sumatra Basin as fractured basement and not only economic basement based on data presented in this article.

Figure 1. Location of research area is shown by the red box (map from Google).
DATA AVAILABILITY & SCOPE OF WORK

The primary data used in this study include seismic and well data. The seismic data was interpreted and used in building a geological cross section. The well data consist of wireline logs used in stratigraphic correlation and thin sections for describing lithology and pore characteristics and estimating the porosity. Secondary data include published work on the region by previous authors such as Anderson et al. (1993), whose lithostratigraphic subdivision has been used as a reference in this study (Figure 2). All of these data are used to support interpretation for basement prospectivity.

PRE-TERTIARY BASEMENT

The Pre-Tertiary rocks in the North Sumatra Basin consist of limestones and dolomites which underlie the Tertiary sediments. Previous authors suggested that within the Pre-Tertiary rocks, there are also sandstones, metasediments, tuffs, and granites. Drill cuttings from the study area reveal that these carbonates are typically wackestone-packstones, bioclasts, skeletal packestones with fracture and vuggy porosity ranging 5-10%. Porosity estimation from well data reveals porosity range from 5 to 25%. Nevertheless, Caughey and Wahyudi (1993) reported that despite some of the Pre-Tertiary sedimentary rocks were fractured, they are tightly cemented with calcite and quartz and show no reservoir potential. However, observation of core plugs and even dating from these “basement” shows that they are not easily recognized as basement and distinguishing them from the Tampur Formation is difficult.

TAMPUR FORMATION

The name Tampur Formation has been used for all Pre-Oligocene carbonates in the North Sumatra Basin (Collins et al. 1996), but is commonly viewed as Eocene in age (Caughey and Wahyudi 1994, Ryacudu and Sjahbuddin 1994). However, the faunas on which this age is reportedly based have never been documented. Eocene Nummulites limestone is present in West Sumatra, in the Ombilin Basin. But, on the other hand, ‘Basement’ carbonate in the Singa Besar 1 well, just across the Malaysian border in Malacca Straits, contains the Middle-Late Permian foraminifer Shanita and other Permian fauna (Fontaine et al. 1992).

The Tampur formation was described by Ryacudu and Sjahbuddin (1994) as massive, partly biocalcarenites and calcilutites, common dolarenites, chert nodules and basal limestone conglomerates, that indicate deposits of an open marine sublittoral environment.

Figure 2. Stratigraphic column of North Sumatra Basin (Anderson et al., 1993).
From the reports of deep wells in the Aru and Langkat areas, it consists of limestones, commonly fractured and dolomitised (Ryacudu and Sjahbuddin, 1994). Collins et al. (1996) also stated that drill cuttings from the Tampur Formation consist of mudstones, skeletal wackestones, intraclast, oolite packstones, and grainstones. These descriptions show a slightly similar characteristic as those of the Pre-Tertiary basement rocks.

We may conclude that some of the basal limestones in the North Sumatra Basin are of well defined Pre-Tertiary (Permian) age, while Late Eocene limestones may be present as well, similar to the thin foraminiferal carbonates outcropping in the southwestern part of the Central Sumatra basin. If the Late Eocene age interpretation is the correct one, this means that the Tampur sediments are related to syn-rift phase and most likely distinct from the fractured basement rocks.

**SOURCE ROCK AND RESERVOIR CONSIDERATION**

The Tampur Formation was deposited in an open marine shelf setting that generally is lean in organic matter and normally provides poor source material for large scale hydrocarbon generation (Ryacudu and Sjahbuddin, 1994). This means younger sediments are the only possible source for hydrocarbon generation, such as organic-rich shales in the Belumai Formation, Baong Shales, Bampo black shales and in the Meucampli Formation.

There are no specific permeability and porosity data taken from Tampur Formation. However, from cutting description of a well near Aru Bay-1, where 85 meters of thick, fractured dolomites that may correlate to the Tampur carbonates have been drilled, the estimated secondary porosity is around 5-10% (Ryacudu and Sjahbuddin, 1996).

**INTERPRETATION**

Pre-Tertiary basement in the North Sumatra Basin is difficult to be distinguished from Tampur Formation, because it is comprised mainly of wackestone-packstones. At 5990’ and deeper interval in a well (Figure 3), thin sections mostly show that the wacke-packstone is composed of calcite and other minerals, with grains size of around 0.05-0.2mm, subangular-subrounded in grain shape, grain supported and poorly supported, point contact. Matrix consists of sparry calcite type. The rock contains interparticle and fracture types porosity totaling 10%. Another thin section also shows moldic and vuggy porosity. With the integration of well and core porosity that ranges 5-20%, the described characteristics are likely similar to those of Tampur carbonates.

From correlated seismic section (Figure 4) between wells, it can be interpreted that the Tampur Formation is laterally widely distributed. Structural and stratigraphic traps may exist in the

![Figure 3. Photo of thin sections in 5990’ interval of basement carbonates with interparticle and fracture porosity, totaling 10% in porosity.](image)
Tampur Formation. Considering reef buildups could occur along the shelf margin, the fractured Tampur Formation located on the highs as seen on Figure 4 and 5 might contain fair to good porosity and permeability if they had been exposed. This makes them highly prospective for reservoir. The shales of Lower Baong Formation could be the cap rock for the Tampur carbonates reservoir along with its entrapment.

Figure 4. Seismic section of “A” to “E” Well.

Figure 5. Cross section of the study area, red circles indicating the possible accumulation of hydrocarbon for basement fractured. Red arrow indicating the migration pathway.
CONCLUSION

Under certain circumstances, the presence of carbonates in the North Sumatra Basin basement, whether Eocene Tampur Formation or older Pre-Tertiary constituents, suggest that the basement is not an economic basement but fractured basement with potential to be reservoir. However, this study only covered a small portion of the basin and further work is required to prove the prospectivity of the fractured basement.

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REFERENCES


INTRODUCTION

Kali Banyumeneng is located in Mranggen, Demak (Central Java province). The studied outcrop is located approximately 11.25 km to the SE of Semarang city and at the geographic coordinate of 100° 28’ 59.65'' E and 7° 02’ 43.45'' S (Figure 1).

The study area is geologically located in Kendeng Zone, which is also often referred as Kendeng Mountains, an east-west trending anticlinorium in the northern part of Java. The northern border of the Kendeng Zone is Randublatung Depression, while the southern border comprises a line of volcanoes called Solo Zone. Kendeng zone is a continuation of the Northern Mountains Serayu Zone that developed in Central Java. The Salatiga section of the Kendeng zone extends towards the east to Mojokerto and plunges under the Brantas river. The continuation of these mountains can still be tracked under the Madura Strait.

Van Bemmelen (1949) subdivided Kendeng Mountains into 3 parts that consist of the western part, which lies between Mt. Ungaran and Solo (north Ngawi); the central part that lies between Solo and Jombang and the eastern part that extends from east Jombang to Brantas River Delta and continuously to Madura Bay. The study area occurs in the western Kendeng Zone.

Previous work (e.g. van Bemmelen, 1949) shows that the study area consists of two lithostratigraphic units called Kerek and Kalibeng Formations. Kerek Formation consists of interbedded sandstones, claystones, and sandy limestones with observed sedimentary structures such as graded bedding, ripple mark and convolute. Kalibeng Formation is subdivided into lower and upper parts. The lower part of Kalibeng Formation consists of sandstones that shows turbiditic nature. The upper part of Kalibeng Formation is composed of breccias with fragments formed by limestone. The Upper Kalibeng Formation also contains forams, molluscs, corals and algae and it shows a bedding structure.

Observations were carried out to determine the depositional environment model of Kali Banyumeneng area based on lithology, sedimentary structures and fossils.

METHODOLOGY

The observation began with data collection in the field. The field data collection was carried out with stratigraphic section measurement followed by an analysis to determine the depositional environment of the outcrops.
Figure 2. Sedimentological description of Kali Banyumeneng outcrop (to be continued to the next page).
Figure 2. Sedimentological description of Kali Banyumeneng outcrop.
RESULTS

From the results of the 100 meter section measurement, it can be seen that the constituent lithologies are sandstones, limestones, and siltstones (Figures 2 & 3). Sandstones in this area are bright brown in color, with layering structure, and fine to medium in grain size, well sorted and calcareous. The limestone is characterized by gray colour, laminated structure, with coarser grain, poorly sorted, and composed of *Pelecypoda* macrofossil as well as foraminifera fossils. The siltstones in this outcrop are characterized by grayish brown color, no-sedimentary structure, with a silty grain size, well sorted and calcareous.

![Figure 3. Interbedded of limestones and sandstones. Bed thickness increases towards the upstream direction.](image)

The sedimentary structures observed in the Kali Banyumeneng area include bedding, lamination, cross stratification, convolute, load casts, hummocky and ripple marks found on sandstones (Figure 4). Hydrodynamic sedimentary structures are indication of gravitational flow (Boggs, 1987). In addition, the hummocky cross-stratification indicate that the sequence was deposited under storm influence. Mudcracks and rainmarks are also visible in younger sediments probably of Quaternary age.

![Figure 4. Sedimentary structures in sandstone, (A) parallel bedding and (B) ripple marks.](image)

ANALYSIS

Based on our field observation, the Banyumeneng outcrops are interpreted as having deposited in shallow marine to deep water settings. This is indicated by the presence of sedimentary structures exposed on the ground in the form of convolute (identifier slope areas) and the presence of *Pelecypoda*, which usually lives in shallow marine setting. Other indications include sedimentary structures such as hummocky cross-stratification that developed in the area, which have been described above.

REFERENCES


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