DIAGENESIS, COALIFICATION, AND HYDROCARBON GENERATION OF THE KERUH FORMATION, IN KUANTAN-SINGINGI AREA, CENTRAL SUMATERA, INDONESIA

*Rahmat Heryanto *)*

ABSTRACT

The Eocene-Oligocene Keruh Formation is exposed in the western part of Kuantan-Singingi area, southwest margin of the Central Sumatera Basin. It is correlated to the Pematang Group in another part of the Central Sumatra Basin and is also to the Kelesa Formation in the Tigapuluh Mountains. The formation is composed of conglomerate and well-bedded sandstone in the lower part, interbedded mudstone and coal seams in the middle part, and mainly made up of laminated to well bedded light-dark grey to blackish organic-rich mudstones in the upper part of succession. It was deposited in a fluviatile to a lacustrine environment with some marine condition influences.

Diagenetic processes which occurred in the Keruh Formation are compaction and formation of authigenic mineral and secondary porosity. The compaction effects are illustrated by the presence of bending of mica flakes and by grains supported fabrics with long grain contact as well as clay mineral oriented. The formation of the authigenic minerals is recorded by the presence of authigenic quartz and clay minerals, and also quartz overgrowths. The secondary porosity occurrence is caused by a dissolution of the feldspar and clay minerals. The diagenetic stage of the Keruh Formation is included into a mesogenetic semi-mature to mature "A" which equal to mudrock stage II.

Based on the maturity of this Formation reflectance within dispersed organic matter (d.o.m.) and coal of the Keruh Formation, the naturity of this Formation is included into an immature to early mature stage, whereas based on the T_{max} and Hydrogen Index (HI) values, the the kerogen within the Keruh Formation is categorized into a late immature to early mature level.

There is a relationship between diagenetic stage and maturation of organic matter which was caused by the burial history with the depth of burial between 2000 to 3000 m, which produced the paleo temperature of 65° to 95°C.

Keywords: Keruh Formation, diageneses, authigenic mineral, thermal maturation

SARI

Formasi Keruh berumur Eosen-Oligosen tersingkap di sebelah barat daerah Kuantan Singingi, tepi barat laut Cekungan Sumatera Tengah. Formasi ini dikorelasikan dengan Kelompok Pematang di bagian lain Cekungan Sumatera Tengah, dan juga Formasi Kelesa di Pegunungan Tigapuluh. Formasi ini tersusun oleh konglomerat dan batupasir berlapis di bagian bawah, perselingan batulumpur warna kelabu dan batubara dengan sisipan batupasir di bagian tengah, dan batulumpur warna kelabu terang-gelap sampai kehitaman, kaya akan bahan organik, laminasi sampai berlapis baik di bagian atas. Formasi ini terendapkan dalam lingkungan fluviatil sampai lakustrin dengan sedikit pengaruh laut.

Proses diagenesis yang terjadi dalam Formasi Keruh adalah kompaksi dan pembentukan mineral autigenik dan porositas sekunder. Kompaksi dicirikan oleh adanya pembengkokan mineral mika dan kemas yang didukung oleh butiran dengan kontak sepanjang butiran, selain itu juga adanya pengarahan mineral lempung. Pembentukan mineral autigenik dicirikan oleh adanya mineral, yang disebabkan oleh pelarutan mineral felspar dan mineral lempung. Tingkat diagenesis Formasi Keruh termasuk ke dalam mesogenetik semimatang sampai matang "A" atau sama dengan "batulumpur" tingkat II.

Berdasarkan reflektan vitrinit di dalam *d.o.m*. dan batubara dalam Formasi Keruh, kematangan termal formasi ini termasuk dalam tingkat belum matang sampai awal matang, begitu juga berdasarkan Tmax dan Indeks hidrogen yang menunjukkan tingkat belum matang akhir sampai matang awal.

Adanya hubungan antara tingkat diagenesis, pembatubaraan dan kematangan batuan sumber hidrokarbon disebabkan oleh proses sejarah penimbunan dengan kedalaman timbunan antara 2000 sampai dengan 3000 m, yang menghasilkan temperatur purba 65° sampai dengan 95°C.

Kata kuncu : Formasi Keruh, diagenesis, mineral autigenik, kematangan termal

*) Pusat Survei Geologi

INTRODUCTION

The Keruh Formation is a new proposed formation (Kusumahbrata and Suwarna, 2003) having a type locality exposed along the stream of Keruh River, and situated approximately 10 km northwest of the Petai Village, in the northwestern part of Kuantan-Singingi Regency, Riau Province. The area is part of the southeastern margin of Tertiary Central Sumatera Basin, one of the Indonesian oil producing back-arc basins (Figure 1). The basin is underlain by the pre-Tertiary basement rocks, and it has been filled by the Eocene to Plio-Pleistocene siliciclastic-dominated sediments.

The aim of this study is to determine a diagenetic feature of sediments and the coalification of their organic matter relating to hydrocarbon generation within the Keruh Formation. Fieldwork activity including sedimentologic and stratigraphic observations were carried out in the northwestern (Makarya, Manunggal and Nusa Riau coal mining areas), and the southeastern ("TBS" oil palm plantation area) parts of Kuantan-Singingi Regency (Figure 1). Laboratory techniques such as palynological, organic petrology and mineralogy, TOC (Total Organic Carbon), "Rock-Eval Pyrolysis", XRD and SEM analyses were carried out by Geol-Labs, Geological Research Development Centre, Bandung.

GEOLOGICAL SETTING

The basement of Tertiary Central Sumatera Basin is occupied by the Permo-Carboniferous Kuantan Formation, which comprises Lower Member (quartzite and quartz sandstone interbedded with slate, phyllite, shale, volcanic rock, chloritic tuff, conglomerate, and chert), Limestone Member (limestone, slate, phyllite, silicified shale, and quartzite), and Phyllite and Shale Member (phyllite and shale intercalated with slate, quartzite, siltstone, chert, and lava flow). The Kuantan Formation overlied unconformably by the Triassic Tuhur Formation, which consisted of Limestone Member (sandy and conglomeratic limestones), and Slate and Shale Member (slate, shale, marly shale interbedded with radiolarian chert, black silicified shale and thinly bed metamorphosed greywacke). These Pre-Tertiary rocks are intruded by Triassic-Jurassic granitic rocks consisting of granite, granodiorite, and quartz porphyry (Silitonga and Kastowo, 1995; Figure 2).

The Tertiary succession consists of Telisa Formation comprising Lower and Upper Members. The rock unit studied is a portion of the Lower Member of Telisa Formation which consists of marly claystone, sandstone, lignite, tuff andesitic, breccia, and glauconitic sandstone (Silitonga and Kastowo, 1995; Figure 2). Based on the palynological analyses, Kusumahbrata and Suwarna (2003) introduced this unit as the Eocene-Oligocene Keruh Formation which may be correlated to part of the Pematang Group of the Central Sumatra Basin and the Kelesa Formation in the Tigapuluh Mountains. Moreover, the Lower Member of Telisa Formation is correlated to the Sihapas Formation in Central Sumatra Basin and the Lakat Formation in the Tigapuluh Mountains. The Upper Member of the Telisa Formation consists of shale and marly limestone with thinly intercalation of andesitic tuff of an Early to Middle Miocene age. The member is known as the Telisa Formation in Central Sumatera Basin and is correlated to the Gumai Formation in Tigapuluh Mountains (Suwarna *et al*., 1994).

The Late Miocene-Pleistocene Palembang Formation conformably overlies the Telisa Formation. This formation is correlated to the Petani Formation in the Central Sumatera Basin. The Palembang Formation consists of the Lower Member (mudstone with some interbeds of sandstone and glauconitic sandstone) called as the Airbenakat Formation in the Tigapuluh Mountains, while the Middle Member (sandstone, sandy mudstone with interbeds of coal and tuff) called as the Muaraenim Formation in the Tigapuluh Mountains, and the Upper Member (acid tuff containing pumice, tuffaceous sandstone, bentonite, and interbedded lignite and silicified wood) which is called as the Kasai Formation in the Tigapuluh Mountains (Suwarna *et al.*, 1994), and is known as the Minas Formation in the Central Sumatera Basin.

SEDIMENTOLOGY OF KERUH FORMATION

The Eocene-Oligocene Keruh Formation comprises conglomerate which upward is followed by well bedded sandstone with intercalation of parallel laminated mudstone (Photo 1) in the lower part. Then this sequence is overlain by alternating of coal seams, carbonaceous shale and mudstone, with some inteebedded of sandstone in the middle part. Interbedded laminated shale and mudstone occupy the upper part of the formation (Heryanto *et al*., 2004; Figure 3).

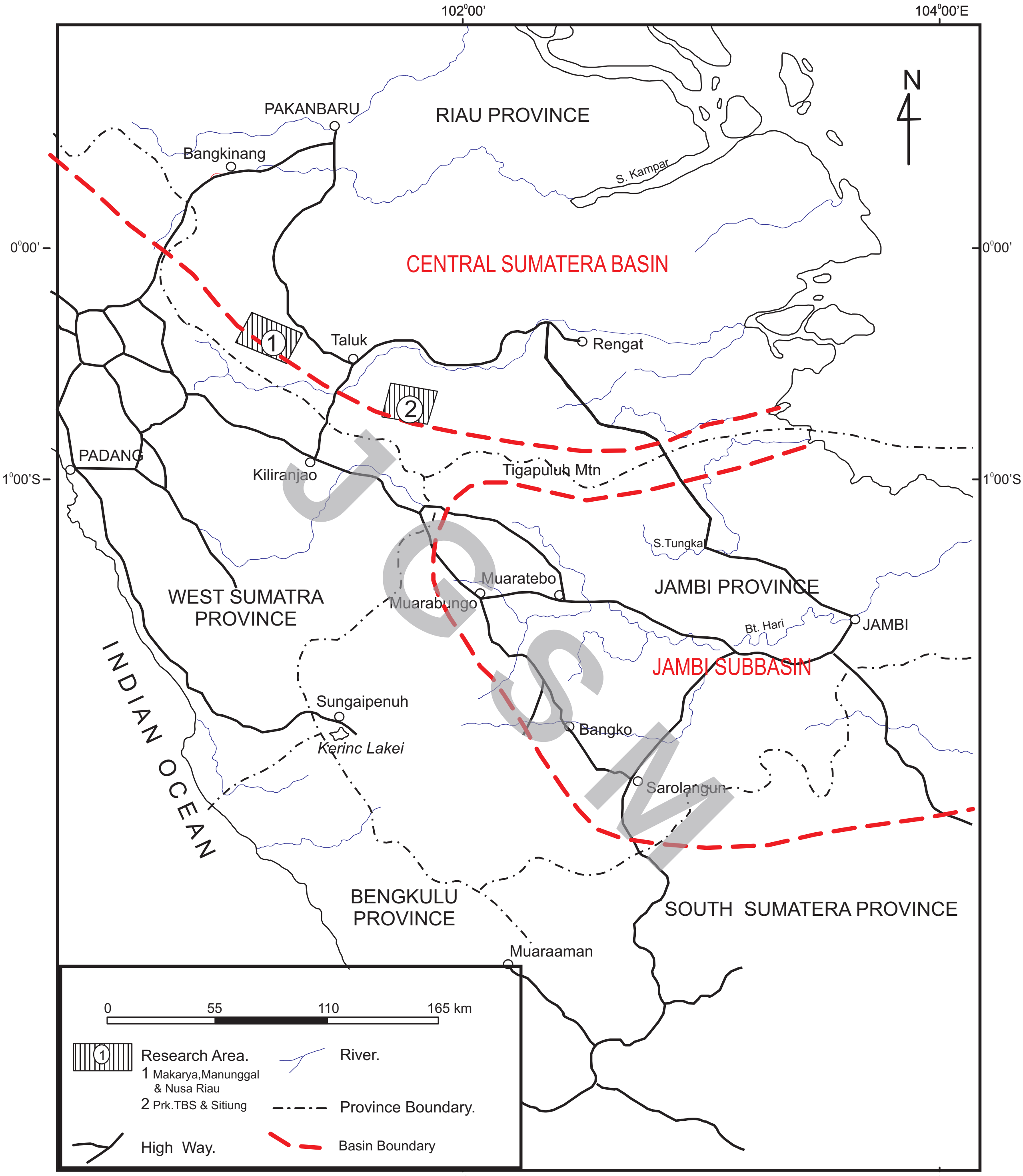

Figure 1. Locality map of the Central Sumatera Basin and study areas.

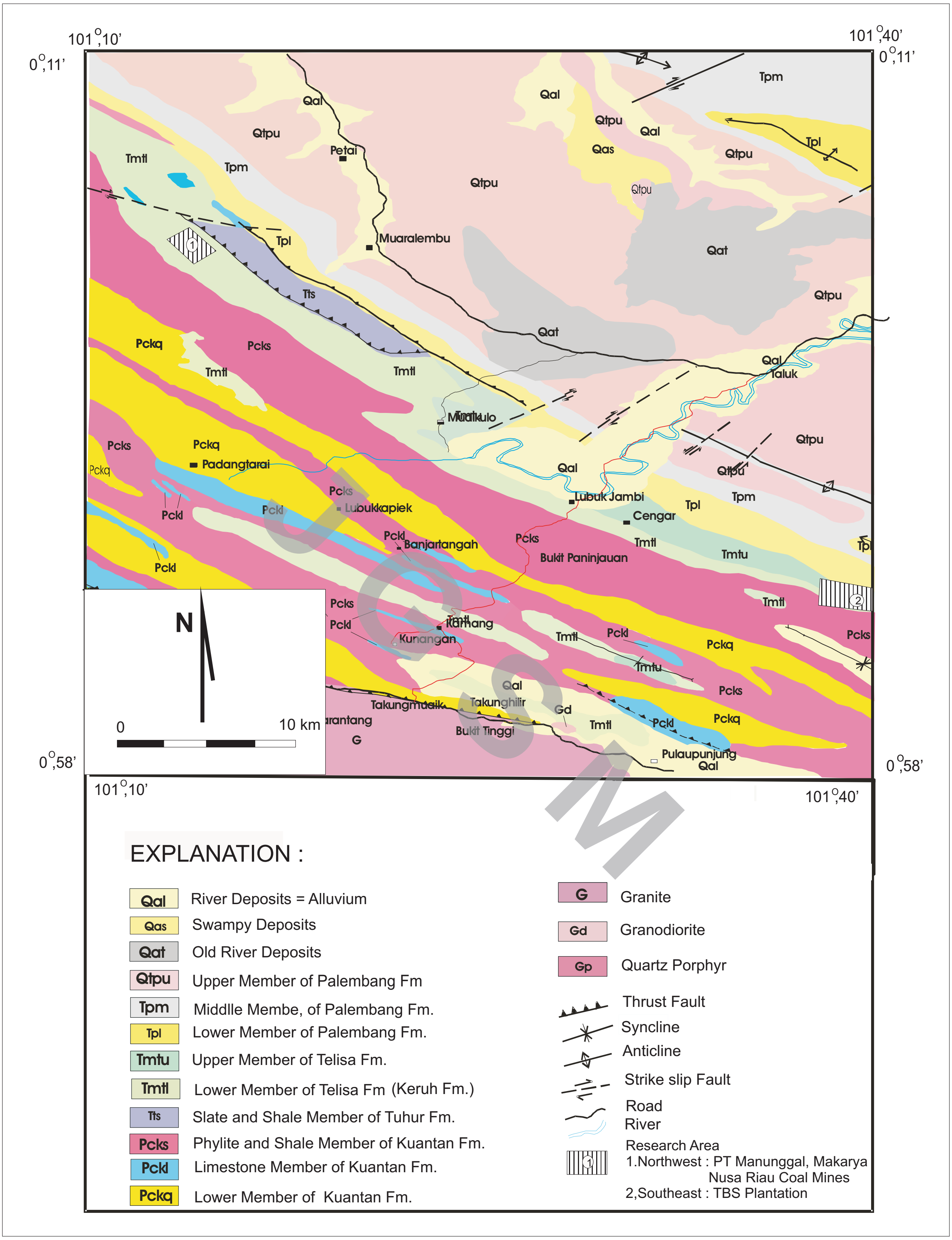

Figure 2. Geological Map of the Taluk and surounding area (Silitonga & Kastowo, 1995).

Well bedded Sandstone (10-50 cm in thickness), medium to coarse-grained, comprises dominantly quartz with some feldspar and lithic fragment. Shale and mudstone, light to blackish grey, flaky to thickly laminated, show a parallel lamination (Photo 2) in places, abundant organic material and contain iron oxide veinlets. Physically, these rocks are hard when fresh and soft when altered and wheathered. These rocks are also interbedded with a light grey mudstone having a poor organic matter content. These shale and mudstone beds are well developed in the PT Nusariau coal mining area, with the bedding thickness ranges from 0.5 to 5 m. In northwestern and southeastern parts of studied area, some interseam sediment within coal seams, consisting of dark grey to black shale are recognized. Coal seams are black, dull to bright banded, vitrous luster, conchoidal fractures. The thickness of the coal seams is ranging from 0.5 to 8 m (Figure 3).

The presence of *Palmaepollenites kutchensis, Florschuetzia trilobata, Cicatricosisporites dorogensis, Verrucatosporites usmensis* and *Retistephanocolpites williamsii* shows that the formation is a Late Eocene in age. The Keruh Formation covered by the Lakat Formation (Midle-Late Oligocene), therefore, the suitable age for the Keruh Formation is a Late Eocene to Early Oligocene. On the basis of lithological characteristics, the lower part of the Keruh Formation was deposited in the fluvial system, whilst the middle part was accumulated in the swampy area, interconnected with floodplain or upper part deltaic system. The upper part of the formation comprises interbedded laminated shale and mudstone of light to blackish grey, flaky to thickly laminated, showing a parallel lamination (Figure 4), which represented a lacustrine depositonal environment. The presence of *Palmaepollenites kutchensis, Florschuetzia* sp., *Durio* sp., *Discoidites borneensis, fungal spore* and *small diatomea*, however, tends to show a littoral or fresh water conditions. The appearance of telalginite and Botryococcus, and also the presence of framboidal pyrites indicate that a marine condition occurred. Thereby, the suitable depositional

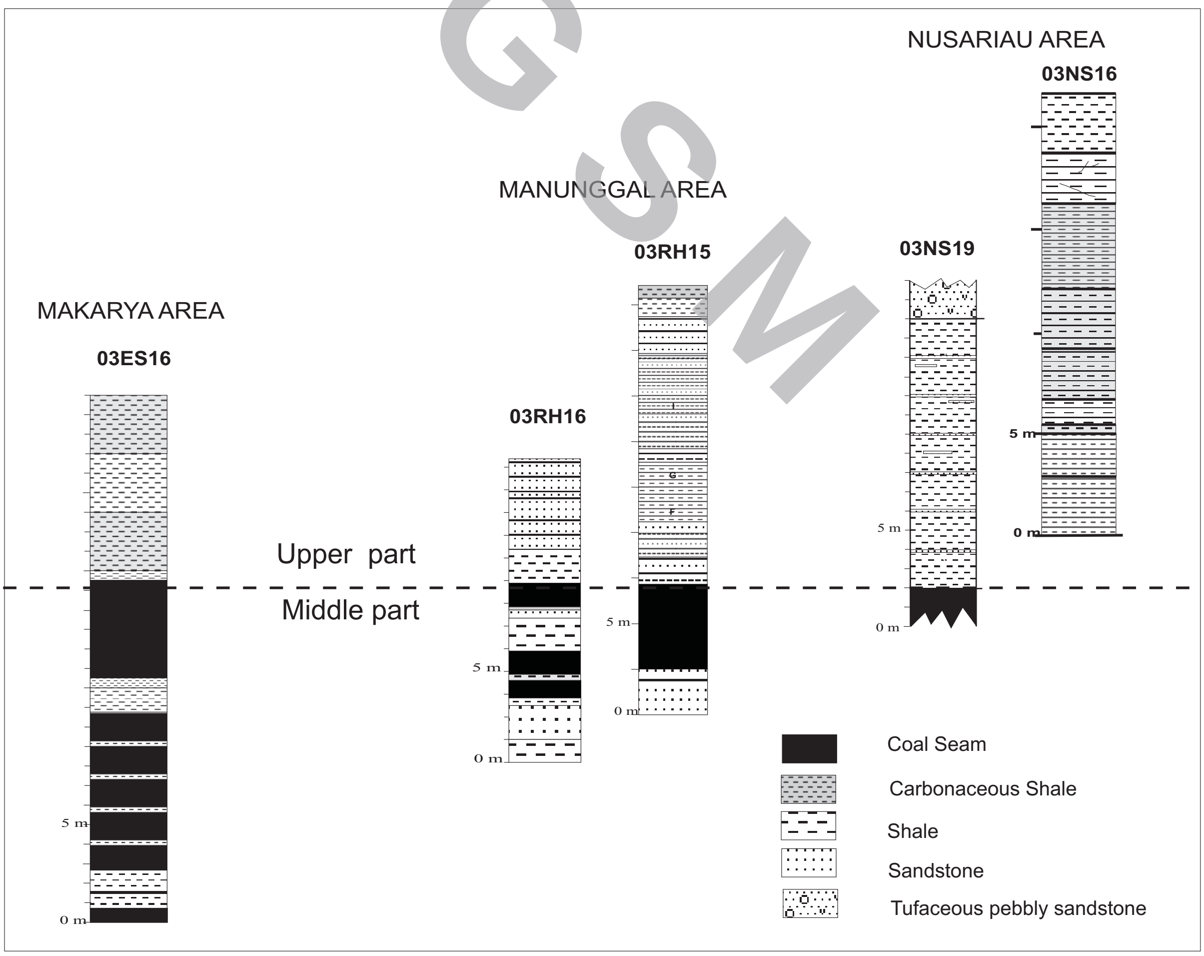

Figure 3. Columnar section of the upper and middle parts of Keruh Formation in the northwestern part of the studied area based on the lithological appearance.

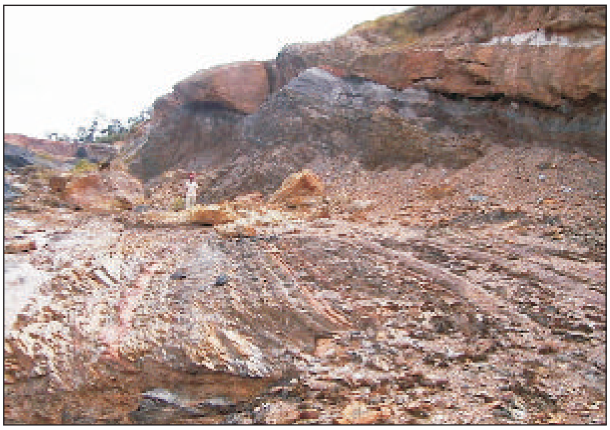

Photo 1. Outcrop of thickly bedded - massive coarse-grained sandstone, relatively sitting above the intercalation of thinly bedded mudstone and fine-grained sandstone. Location : PT Manunggal Area.

Photo 2. Outcrop of laminated carbonaceous shale and mudstone, grey to blackish colour, flaky to thickly lamination, as upper part of the Keruh Formation. Location : PT. Nusa Riau area.

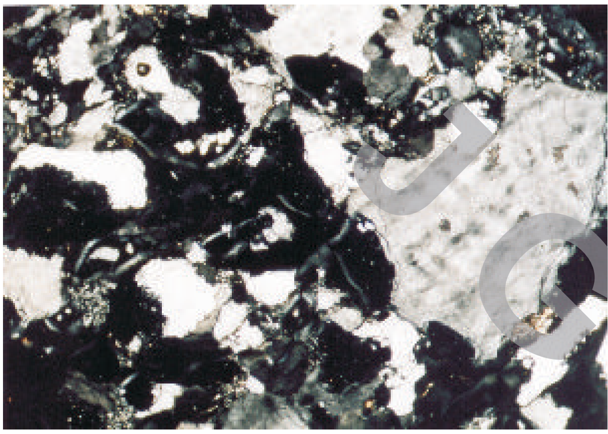

Photo 3. Photomicrograph of quartz sandstone from PT Manunggal , shows that the sandstone has already compacted. Quartz overgrowth (o) also found in some quartz grain (Q) (Kusumahbrata and Suminto, 2003). Sample Number : 03SG06A.

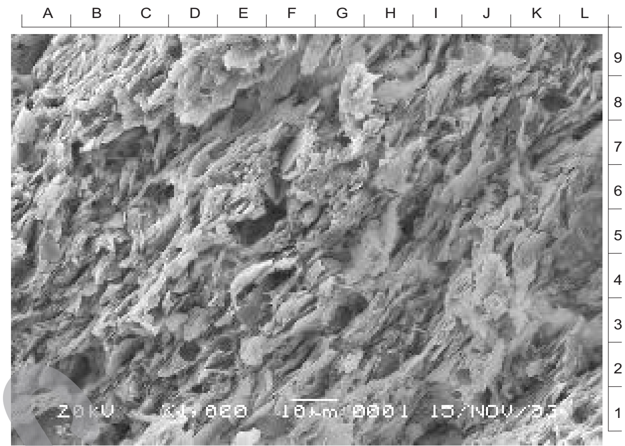

Photo 4. Photomicrograph of SEM of shale from PT Nusa Riau, shows a close up oriented clay minerals of dominated illite with some smectite, kaolinite and calcite (Panggabean 2003a). Sample Number : 03NS16A.

environment for the Keruh Formation is a fluvial system in the lower part, a swampy area interconnected with flood plain in the middle part, and a lacustrine with some influence of marine conditions in the upper part.

DIAGENESIS

Diagenesis is the process involving all the physical, chemical and biological changes in the sediment after deposition, during and after lithification (Larsen and Chilingar, 1979; Chilingarian, 1983). Based on the petrographic, Scanning Electron Microscopic and X-ray Diffraction studies on the sedimentary rock samples of the Keruh Formation show a variety of diagenetic feature as a result of diagenetic processes, such as compaction and the formations of authigenic minerals and secondary porosity.

Compaction characters within sandstone samples, are reflected by grain supported fabric with some long grain contacts, the bending of mica flakes, and quartz grains that might be strained or fractured (Photo 3). In mudstone samples, compaction is illustrated by clay minerals oriented such as illite, smectite and kaolinite (Photo 4). Compaction will reduce the primary porosities. These diagenetic features appear to be caused by the deeply buried.

Authigenic minerals which occurred within the the Keruh Formation are quartz and clay minerals. Authigenic quartz comprises quartz overgrowths and euhedral crystals quartz. Quartz overgrowths (Kusumahbrata and Suminto, 2003) are commonly found only within the quartz sandstone (Photo 3), whereas the euhedral crystal quartz (Photo 5), is not only found within the sandstone, but also found within the mudstone as a pore filling.

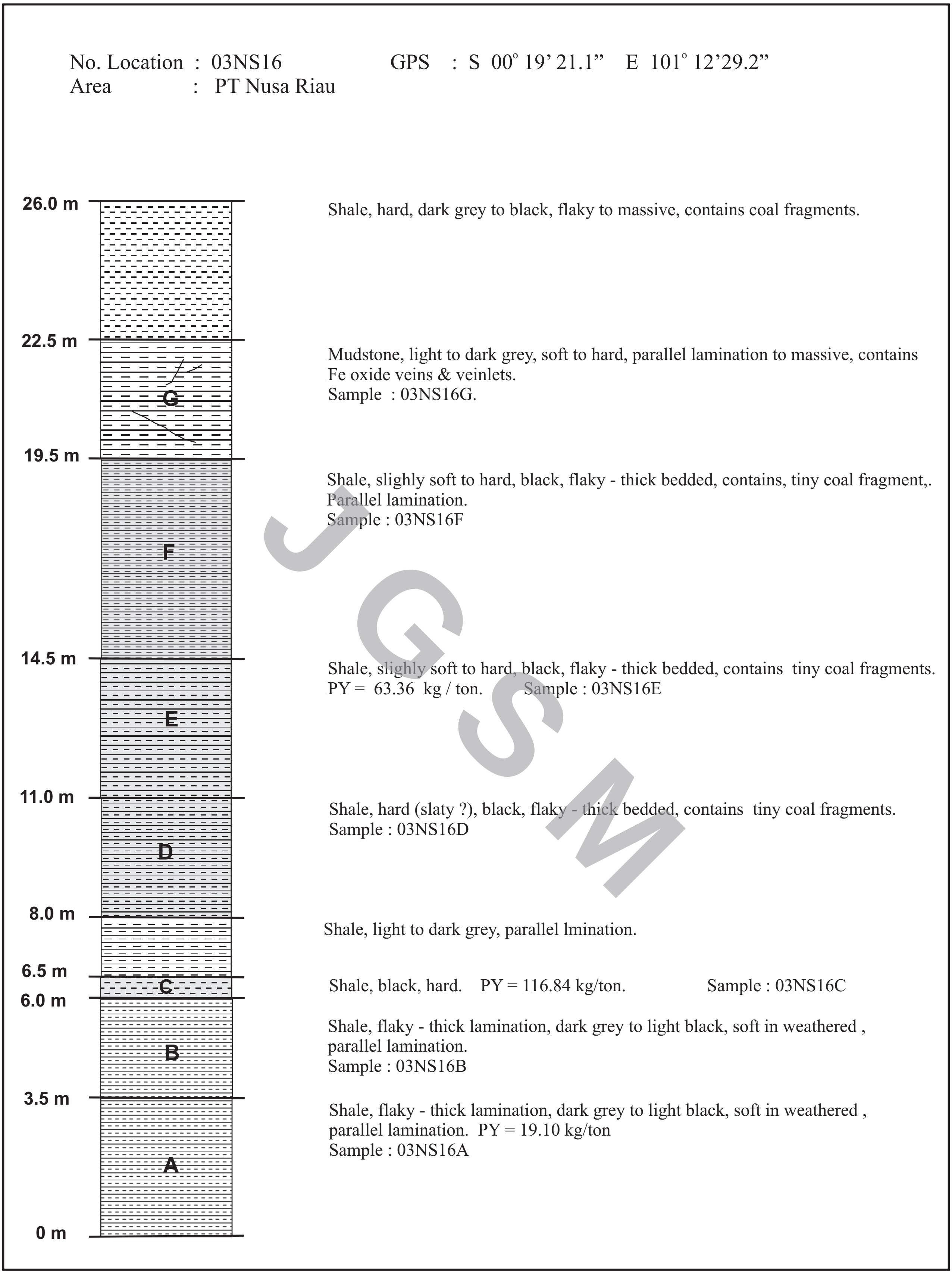

Figure 4. Measured section of the upper part of Keruh Formation at location 03NS16 in the Nusa Riau coal mining area, which representing lacustrine environment.

Authigenic clay minerals are clearly identified by XRD (Table 1; Panggabean, 2003b) and SEM (Photos 5 and 6; Table 2; Panggabean 2003a) analyses. These authigenic clay minerals are found within both sandstone and mudstone. They comprise dominantly kaolinite, with some illite, and smectite. Some authigenic illite minerals appear as a mixed-layer clay with smectite.

Secondary porosities within the sandstone present as a dissolution of feldspar and volcanic fragments, whereas within the mudstone they appear as a dissolution of clay minerals which produced a pore with having 2-20 microns in diameter sized (Panggabean, 2003a).

Classifications of diagenetic stage were introduced by several authors such as Schmidt and McDonald (1979), Helmod and van de Kamp (1984), Pettijohn *et al*. (1987), and Burley *et al*. (1987). Compaction is a diagenetic process which is indicated by physical changes in the sediment after deposition. According to Helmod and van de Kamp (1984), compaction occurred in an early-shallow subsurface (Group A) up to a late deep subsurface (early Group C).

Chemical diagenesis also occurred since or after deposition, it began with the formation of the authigenic clay minerals in early shallow subsurface. The process was followed by the formation of the quartz overgrowth and euhedral authigenic quartz in the beginning of late deep subsurface or Group B of the Helmod and van de Kamp (1984) classification.

The presence of secondary porosity created by the dissolution within the sandstone of the Keruh Formation, indicated that the diagenetic process occurred in a late-deep subsurface at Group B (Helmod and van de Kamp, 1984).

Based on the diagenitic cycle of Schmidt and McDonald (1979), the sandstone and the mudstone of the Keruh Formation can be equated to the mesogenetic semi mature to mature "A" stage of diagenesis, whereas based on the diagenetic scheme for mudrock (Burley *et al*., 1987), they would be included into mudrock stage II, with temperature in the range from 65° C to 95° C, and the depth of burial ranging from 2000 m up to 3000 m.

COALIFICATION

A reflected light optical method with and without fluorenscence mode is used in the organic petrology, with the main advantages are to discriminate and locate organic matter of different types of macerals, and to measure their respective ranks of evolution. Dispersed organic matter (DOM) found within the carbonaceous mudstones in the Keruh Formation is presented in Table 3, whereas the petrographic result of coal samples is shown in Table 4. The information on the thermal evolution of organic matter, particularly is based on the vitrinite reflectance measurements. The vitrinite reflectance is considered as one of the best parameter to define coalification stages (Photo 6).

Maceral analysis, using optical organic petrography performed on eighteen shale and mudstones samples (Table 3), shows that the DOM of the Keruh Formation is predominated by exinite (liptinite) group

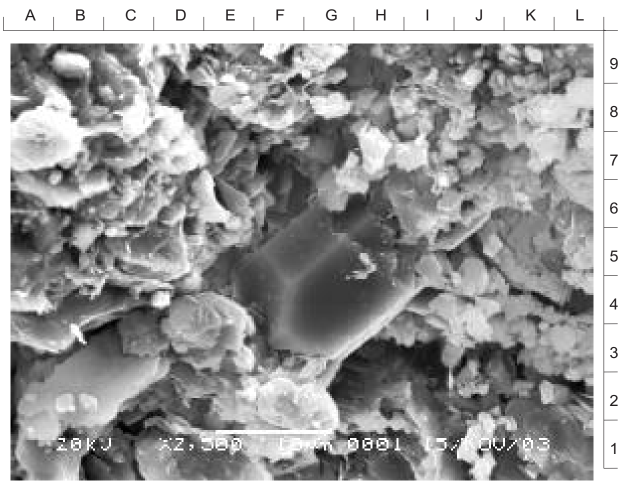

Photo 5. Photomicrograph of SEM of sandy mudstone from PT Manunggal, shows an authigenic quartz (E-I, 3-6) and clay minerals of kaolinite, smectite and illite (Panggabean, 2003a). Sample Number : 03SM08.

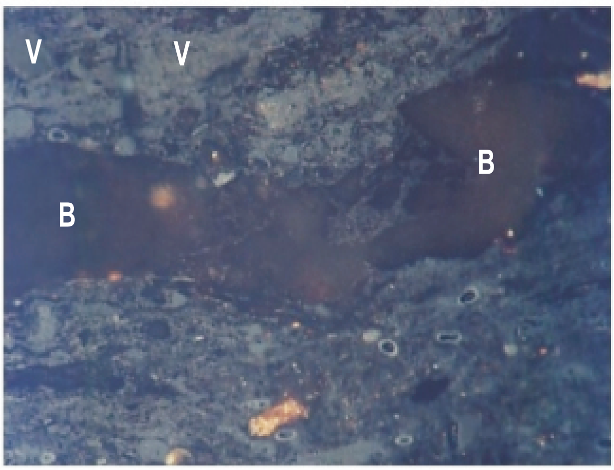

Photo 6. Photomicrograph of organic petrography of rock sample 03RH13C, at normal reflected light. Shows a vitrinite maceral (V) dan bitumen (B). Magnification 350 X.

Table 1. X-Ray Diffraction (XRD) Analysis Results, of Rock Samples From Kuantan-Singingi Area, Riau Province (Panggabean, 2003b).

No.	Sample No.	Q (%)	K (%)	I (%)	Sm (%)	Sm-I (%)	Ca (%)	Fe (%)	Sd (%)	Explanation
1	03SM-05	96.0	2.3	0.8	0.7	0.2	0.0	0.0	0.0	**Abreviation:** Q = Quartz Kaol = Kaolinite Ca = Calcite I = Illite Sm = Smectite (Montmorolionite) Sm-I = Mixed layer smectite and illite Fe = Hematite Sd = Siderite
2.	03SM-08	96.0	2.8	0.6	0.6	0.0	0.0	0.0	0.0	
3	03SM-11	94.2	2.8	1.7	0.9	0.4	0.0	0.0	0.0	
4	03SM-14A	93.5	3.6	1.4	0.7	0.8	0.0	0.0	0.0	
5	03SM-17A	96.0	2.4	0.6	0.6	0.4	0.0	0.0	0.0	
6	03SM-20	95.8	3.6	0.0	0.6	0.0	0.0	0.0	0.0	
7	03SG-06A	67.2	7.7	9.4	0.0	0.0	0.0	0.0	15.7	
8	03SG-07A	97.3	1.4	0.7	0.3	0.3	0.0	0.0	0.0	
9	03SG-08B	72.7	4.7	2.5	0.7	1.5	15.1	2.8	0.0	
10	ES-13A	40.2	5.6	1.2	0.0	0.0	53.0	0.0	0.0	
11	NS-13A	72.6	23.0	0.0	4.4	0.0	0.0	0.0	0.0	
12	NS-16A	69.7	6.4	13.3	0.6	7.0	3.0	0.0	0.0	

Table 2. Summary of SEM data of Kuantan-Singngi rock samples (Panggabean, 2003a)

No Sample	Lithology	Composition	Clay Minerals	Texture/Structure Of Clay minerals	Element of "fosil fuel"	Diagenetic Features	Diagenetic Stage	Remark
03ES13A	Shale	Calcite, kaolinite a few illite	Kaolinite & illite	Laminated & oriented	-	Compaction &auth. Clay mins	Early Mesodiagenesis	More than 1000 m buried
03NS13A	Mudstone	Kaolinite, smectite & some illite	Kaolinite, smectite & some illite	Disoriented	Sporinite & drop oil	Compaction &auth. Clay mins	Early Mesodiagenesis	More than 1000 m buried
03NS16A	Shale	Illite, kaolinite & some calcite	Illite & kaolinite	Well oriented	-	Compaction &auth. Clay mins	Early Mesodiagenesis	More than 1000 m buried
03SG02A	Shale	Kaolinie, illite, smectite, org. pyrte	Kaolinite , illite smectite	Laminated and oriented	Vitrinite	Auth. Clay mins	Late Eodiagenesis	Less than 1000 m buried
03SG04A	Shale	Illite with some smectite	Illite , smectite	Lamnated, well oriented & curly	-	Compaction &auth. Clay mins	Early Mesodiagenesis	More than 1000 m buried
03SG06A	Mudstone	Kaolinite and illite	Kaolinite and illite	Disoriented	-	Compaction &auth. Clay mins	Early Mesodiagenesis	More than 1000 m buried
03SG07A	Fine-grained sandstone	Qrtz, flpr, kaolinite & smesctite	Kaolinite and smectite	Book texture	-	Compaction &auth. Clay mins	Early Mesodiagenesis	More than 1000 m buried
03SG08B	Fn to med-grained sandstone	Qrtz, flpr, kaolinite smectite, illite	Kaolinite, smectite & illite	Disoriented	-	Compaction &auth. Clay mins	Early Mesodiagenesis	More than 1000 m buried
03SM01A	Mudstone	Smectite and illite	Smectite and illite	Disoriented	-	Compaction &auth. Clay mins	Early Mesodiagenesis	More than 1000 m buried
03SM05	Mudstone	Kaolinite, illite & smectite	Kaolinite, illite & smectite	Disoriented	-	Compaction &auth. Clay mins	Early Mesodiagenesis	More than 1000 m buried
03SM08	Shale, flaky	Calcite, kaolinite & illite	Kaolinite & illite	Mostly oriented and laminated	-	Compaction &auth. Clay mins	Early Mesodiagenesis	More than 1000 m buried
03SM11	Mudstone	Kaolinite & a few smectite	Kaolinite and smectite	Book and vermicular textures	-	Compaction &auth. Clay mins	Early Mesodiagenesis	More than 1000 m buried
03SM16	Sandy mudstone	Qrtz, flpr, kaolinite & smectite	Kaolinite and snectite	Disoriented	-	Compaction &auth. Clay mins	Early Mesodiagenesis	More than 1000 m buried
03SM17A	V. fn. sandstone	Qrtz, flpr, kaolinite smectite, illite	Kaolinite, smectite & illite	Disoriented	-	Compaction &auth. Clay mins	Early Mesodiagenesis	More than 1000 m buried
03SM20	Fn. Sandstone	Qrtz, flpr, kaolinite & smectite	Kaolinite and smectite	Disoriented	-	Compaction &auth. Clay mins	Early Mesodiagenesis	More than 1000 m buried

Table 3. Result of Maceral Analysis (DOM) of Rock Samples of the Keruh Formation, Kuantan - Singingi

No	Sample No.	Maceral (%)									Area
		Resinite	Cutinite	Liptodetrinit	Alginite	Bitumen	Exinite	Rv min	Rv max	Rv	
1.	03 ES 16 L	2,4	-	1,6	1,2	-	5,2	0,19	0,40	0,25	Makarya
2.	03 ES 16 M	0,8	-	-	0,4	0,4	1,6	0,36	0,53	0,45	Makarya
3.	03 ES 16 N	0,2	-	-	-	-	0,2	0,22	0,37	0.27	Makarya
4.	03 NS 16 A	0,6	-	-	-	0,4	1,0	0,41	0,43	0,42	NusaRiau
5.	03 NS 16 C	0,8	-	0,4	0,4	-	1,6	-	-	-	NusaRiau
6	03 NS 16 E	0,6	-	-	-	-	0,6	0,40	0,53	0,46	NusaRiau
7.	03 NS 19 A	-	-	-	-	-	-	0,41	0,56	0,49	NusaRiau
8.	03 NS 19 D	0,2	0,4	-	-	0,2	0,8	0,23	0,29	0,26	NusaRiau
9.	03 RH 15 E	0,2	-	-	-	-	0,2	0,28	0,49	0,38	Manunggal
10.	03 RH 15 G	-	-	-	-	-	-	0,34	0,48	0,42	Manunggal
11.	03 RH 15 J	0,4	-	0,6	-	0,4	1,4	0,48	0,61	0,57	Manunggal
12.	03 RH 17 F	-	-	-	-	-	-	0,60	0,70	0,66	Manunggal
13.	03 ES 13 A	2,8	-	-	4,6	-	7,4	0,31	0,58	0,47	Prk.TBS
14.	03 ES 13 H	1,2	-	-	1,2	2,4	4,8	0,33	0,37	0,35	Prk.TBS
15.	03 RH 12 A	-	-	-	-	-	-	0,12	0,26	0,19	Prk.TBS
16.	03 RH 13 C	1,6	0,4	0,8	0,4	0,6	3,8	0,26	0,38	0,35	Prk.TBS
17.	03 NS 13 A	0,6	-	-	0,4	0,8	1,8	0,24	0,37	0,30	Sitiung
18.	03 RH 13 C	1,6	0,4	0,8	0,4	0,6	3,8	0,26	0,38	0,35	Sitiung

Rv min : Minimum vitrinite reflectance   Rv max. : Maximum vitrinite reflectance   Rv : Mean vitrinite reflectance.

(0.2-7.4%). The exinite group comprises alginite (0.4-4.6%) such as lamalginite and Botryococcus type alginite. Other macerals are resinite (0.2-2.8%), bitumen and bituminite (0.2-2.4%), with some cutinite (0.4%) and liptodetrinite types(0.4-1.6%). Vitrinite reflectance (Ro max), measured in the DOM within the formation, ranges between 0.26 and 0.70%.

Organic petrography analysis on ten coal samples of the Keruh Formation is shown in Table 4. The composition of the maceral group is vitrinite (54-94%), inertinite (< 1.8%) and exinite (< 8.8%). The vitrinite reflectance ranges from 0.37% to 0.56%. The exinite maceral group is a maceral group which supports the generation of the oil in the source rock. The exinite group found within the coal samples consists of resinite (< 2%), sporinite (< 0.4%), cutinite (< 7%), exsudatinite and alginite (< 0.2%).

The coalification of dispersed organic mater (DOM) within the shale and mudstone, and coal seams in the Keruh Formation is expressed by the vitrinite reflectance (Table 3). The average vitrinite reflectance (Rv) of the DOM within the shale and mudstone samples ranges from 0.19% to 0.66% (Table 3). The lowest average vitrinite reflectance (Rv) value is 0.19% and the highest value is 0.26%, whereas the lowest value of the vitrinit reflectance maximum (Rv max) is 0.26%, and the highesr value is 0.70%. General correlation of organic maturation indices diagram (Kantsler *et al*., 1978), indicates that the organic maturation of DOM within the shale and mudstone categorized as immature to early mature stage, which caused by burial coalification up to 2500 m and the paleo-temperature up to 80°C.

The vitrinite reflectance within the coal samples ranges from 0.37% to 0.56% (Table 4). The relationship of coal rank to terms for diagenesis and metamorphism (Cook, 1982), indicates that the coalification of coal seams in the Keruh Formation is equivalent to the early mesodiagenesis (Foscolos et al, 1976). The general correlation of organic maturation indices diagram, however, indicates that the organic maturation of the coal samples is defined as immature to very early mature stage, which was caused by burial coalification with depth of less than 2000 m and the paleo temperature of up to 70°C.

Based on these data, the coalification stage of organic materr within shale, mudstone, and coal seam of the Keruh Formation is equal to eodiagenesis to early mesodiagenesis stage, and it was also termed into immature to early mature stage, which caused by the burial process at a depth of burial is about 2000 m up to 2500 m, and the paleo-temperature ranges from 70°C to 80°C.

HYDROCARBON GENERATION

In order to analyze a source rock maturation, the organic geochemistry such as total organic carbon (TOC) analysis and Rock-Eval pyrolysis are conducted on eighteen samples from the Keruh Formation (Table 5). Pyrolytic assay provides information on generation potential (ultimate hydrocarbon yield) and expected hydrocarbon product (gas and/or oil). Furthermore, the Rock-Eval pyrolysis, with its limitations, can be used to characterize the type of organic matter and the general nature of the hydrocarbon product (eg. oil versus gas) which will be generated upon thermal maturation (Espitalie *et al*., 1977; Katz, 1983). Source rocks are fine-grained sedimentary rocks containing a high volume of usually autochthonous kerogen from which significant amount of oil may be extracted by pyrolysis. The analyses were carried out in PPTMGB-Lemigas, Jakarta.

Its measurement is extended to particles of disseminated organic matter (DOM) of kerogen occurring in shales and mudstones. Thermal evolution of the source rocks, during diagenesis, catagenesis, and metagenesis, will change many physical or chemical properties of the organic matter. These properties are considered to be indicators for hydrocarbon source rock maturation.

A diagram of Hydrogen Index (HI) versus Tmax as shown in Figure 5 indicates that six samples are included into the immature category, whereas eight samples are in a mature category. Samples included to both immature and mature categories are mostly located in the area close to the boundary between immature and mature level, whereas only one sample located in the area which close to the boundary between mature and post mature. This diagram indicates that source rock samples of the Keruh Formation are present as a late immature to early mature condition.

Table 4. Result of Petrographic Analysis of the Makarya Coals

No	Sample No.(03)	Litho type	%																		
			Tl	Dt	Gl	VIT	Sf & F	Sc	Inerto	IN	Re	Sp	Cu	Exud & Alg	EXIN	Clay	Carb	Framb. Pyrite	Non-Framb Pyrite	MM	Rv
1.	ES.16 K	BD	25.0	54.6	-	79.6	-	-	-	-	2.0	-	-		2.0	2.2	0.6	5.8	9.8	18.4	0.44
2.	ES.16 J	B	61.0	32.4	0.6	94.0	0.2	0.4	0.6	0.8	1.0	-	0.4		1.4	2.2	-	0.2	1.2	3.6	0.54
3.	ES.16-I	B	64.0	24.8	-	88.8	-	0.2	0.4	0.6	0.6	-	-		0.6	5.8	-	2.2	2.0	10.0	0.56
4.	ES.16 H1	BD	34.4	39.4	1.6	75.4	0.2	0.2	0.2	0.6	0.2	-	-	-	0.4	2.0	-	9.8	11.8	23.6	0.51
5.	ES.16 H	B	51.0	32.2	0.4	83.6	-	0.4	0.2	0.6	0.6	0.4	1.2	0.2	2.4	0.4	-	8.0	5.6	13.4	0.42
6.	ES. 16G	DB	6.0	48.0	-	54.0	0.2	1.0	0.6	1.8	-	-	-		-	30.0	-	9.6	4.6	44.2	0.37
7.	ES.16 E	B	56.0	30.0	-	86.0	0.2	0.4	0.2	0.8	1.6	-	7.0	0.2	8.8	-	-	1.2	3.2	4.4	0.54
8.	ES.16 D	B	55.6	37.0	0.4	93.0	0.4	0.4	0.4	1.2	0.6	-	-		0.6	0.6	-	2.8	1.8	5.2	0.45
9.	ES.16 B	BD	12.0	64.2	0.4	76.6	-	-	-	-	0.4	-	-		0.4	11.4	-	4.8	6.8	23.0	0.41
10.	ES.16 A	B	43.6	35.8	2.0	81.4	0.2	-	0.2	0.4	0.6	-	0.4		1.0	0.6	0.2	10.0	6.4	17.2	0.39

Notes :

Tl	: Telovitrinite	Sf	: Semifusinite	Re	: Resinite	CLAY	: Clay minerals
Dt	: Detrovitrinite	F	: Fusinite	Sp	: Sporinite	CARB	: Carbonate
Gl	: Gelovitrinite	Sc	: Sclerotinite	Cu	: Cutinite	Framb	: Framboidal
VIT	: Vitrinite	Inerto	: Inertodetrinite	Exud	: Exudatinite	Non Framb	: Non-Framboidal
B	: Bright	IN	: Inertinite	EXIN	: Exinite	MM	: Mineral Matter
BD	: Banded	DB	: Dull Banded	Alg	: Alginite	Rv	: Vitrinite Reflectance

Table 5. TOC and pyrolysis data of rock samples from the Kuantan-Singingi, Riau

No	No. Sample	LITOLOGY	TOC (%)	S_1 Kg/Ton	S_2 Kg/Ton	PY Kg/Ton	PI	Tmax (°C)	HI	AREA
1.	03RH12A	Clyst, gywht, slty	0,20	0,06	0,25	0,31	0,19	TDD	124	Prk TBS
2.	03RH13C	Coaly Shale, blk	23,80	2,67	116,04	118,61	0,02	425	488	Prk TBS
3.	03RH15E	Sh, gy-bmgy,lam slst-sst	0,59	0,06	0,42	0,48	0,13	440	72	Manunggal
4.	03RH15G	Sh, gy	1,35	0,17	1,85	2,02	0,08	440	137	Manunggal
5.	03RH15J	Sh, gy-dkgy	1,86	0,15	2,24	2,57	0,06	440	130	Manunggal
6.	03RH17F	Sh, gy-dkgy	0,68	0,06	0,37	0,43	0,14	441	55	Manunggal
7.	03ES13A	Sh, bmgy-bm, calc, fissile	6,20	0,21	42,88	43,09	0,00	438	692	Prk. TBS
8.	03ES13H	Clyst, dkgy, carb	8,48	4,31	55,36	59,67	0,07	426	653	Prk. TBS
9.	03ES16L	Sh, blk	10,91	1,93	82,60	84,53	0,02	430	757	Makarya
10.	03ES16M	Sh, gy-dkgy, lam, sltst	1,02	0,04	1,47	1,51	0,03	471	144	Makarya
11.	03ES16N	Sh, dkgy, lam, slst	1,60	0,13	2,06	2,19	0,06	435	129	Makarya
12	03NS13A	Clst, gy-dkgy, carb/coaly	27,33	12,75	174,00	186,75	0,07	417	637	Sitiung
13.	03NS13C	Sh, brngy-bm, calc, papery	7,89	0,21	49,10	49,31	0,00	437	623	Sitiung
14.	03NS16A	Sh, blk	2,99	0,66	18,44	19,10	0,03	446	616	Nusa Riau
15.	03NS16C	Sh, blk	12,24	0,98	115,86	116,84	0,01	449	946	Nusa Riau
16	03NS16E	Sh, blk	9,91	0,42	62,94	63,36	0,01	451	635	Nusa Riau
17.	03NS19A	Sh, gy-dkgy	0,88	0,06	1,00	1,06	0,06	TTD	114	Nusa Riau
18.	03NS19D	Sh, gy	1,55	0,06	1,45	1,51	0,04	440	93	Nusa Riau

NOTES :

TOC	:	Total organic carbon	T max	:	Temperature maximum (°C) for hydrocarbon formation from kerogen
S_1	:	Quantity of free hydrocarbon			
S_2	:	Quantity of hydrocarbon from kerogen	HI	:	Hydrogen Index
PY	:	Total hydrocarbon $(S_1 + S_2)$	TDD	:	Un definite
PI	:	Production Index $= S_1 / (S_1 + S_2)$	Sh	:	Shale
Clst	:	Claystone	slst	:	siltstone
ss	:	sandstone	carb.	:	carbonaceous
Calc.	:	calcareous	brngy	:	brown grey
Gy	:	grey	dkgy	:	darkgrey
blk	:	black	Gywht	:	grey white
lam.	:	laminated	Prk. TBS	:	TBS Plantation.

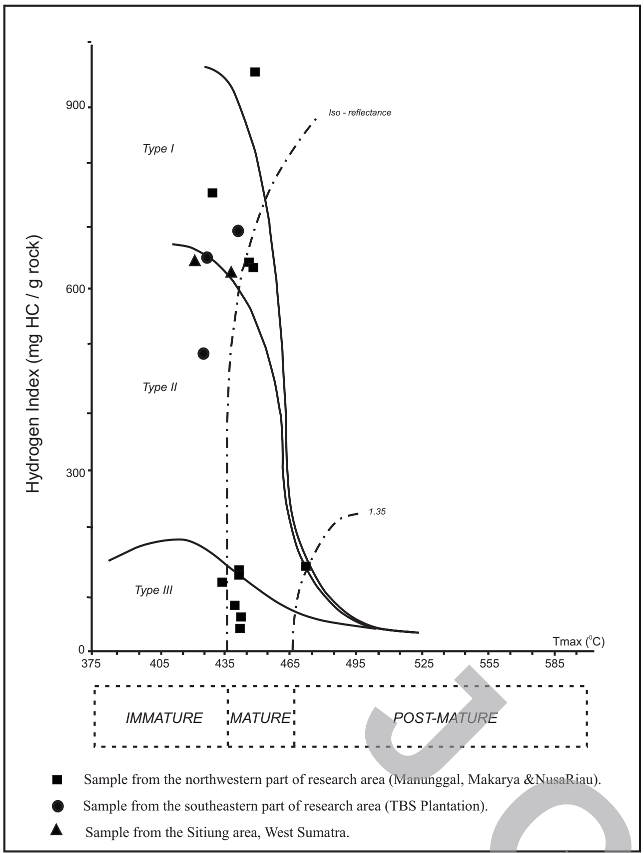

Figure 5. Diagram of Hydrogen Index (HI) Tmax, which shows the kerogen type and the hidrocarbon maturation in the research area.

DISSCUSION

The diagenetic processes which occurred in the sandstone and mudstone of Keruh Formation can be equated to the mesogenetic semimature to mature A stage of diagenetic cycle of Schmidt and McDonald (1979), it would also be included into the mudrock stage II of the diagenetic scheme for mudrock of Burley *et al*. (1987). The diagenetic processes was caused by burial, with the depth of burial ranging from 2000 m up to 3000 m and also temperature in the range of 65°C to 95°C.

The coalification of dispersed organic matter (DOM) found within the carbonaceous mudstones and coal seams in the Keruh Formation, are presented by the value of vitrinite reflectance as 0.26 to 0.70%. The coalification was is equated to eodiagenesis to early mesodiagenesis stage. This relationship was also supported by the presence of authigenic clay mineral of smectite and its mixed-layer clay which equal to those values of the vitrinite reflectance, it is also included to an immature to early mature of hydrocarbon generation stage. These processes are caused by the burial process with the depth of about 2000 m up to 2500 m, and the paleo-temperature ranges from 70°C to 80°C.

This maturity of hydrocarbon generation stage is similar to the diagram of Hydrogen Index (HI) versus Tmax (Figure 5), which indicates that source rock samples of the Keruh Formation are present as a late immature to early mature condition.

Those data indicate that the diagenetic process, coalification and the hydrocarbon source rock maturation of the Keruh Formation are caused by a normal burial process with a depth of burial ranging from 2000 to 3000 m, which produced the paleo-temperature of 65° to 95°C.

CONCLUSIONS

- The diagenetic processes which occurred in the sandstone and mudstone of Keruh Formation can be equated to the mesogenetic semimature to mature "A" stage of diagenetic cycle, it would also be included into the mudrock stage II of the diagenetic scheme for mudrock. The coalification of dispersed organic matter (DOM), which was found within the carbonaceous mudstones and coal seams in the Keruh, are presented by the value of vitrinite reflectance as 0.26 to 0.70%.
- The coalification is equated to eodiagenesis to early mesodiagenesis stage, it is also included to an immature to early mature of hydrocarbon generation stage.
- The diagram of Hydrogen Index (HI) versus Tmax (Figure 5), indicates that source rock samples of the Keruh Formation are present as a late immature to early mature condition.
- These processes are caused by the burial process with the depth of burial ranging from 2000 to 3000 m, which produced the paleo-temperature of 65° to 95°C.

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