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Diagenesis and Provenance of Lati Sandstones in the Berau Area, East Kalimantan Province, based on Petrography Data

Diagenesis dan Asal Batupasir Formasi Lati di Daerah Berau, Provinsi Kalimantan Timur, berdasarkan Data Petrografi

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Abstract

This study is focused on the provenance and diagenetic processes affecting the sandstones of Lati Formation cropping out at Berau Area, East Kalimantan Province. Petrographic analysis of twenty-two samples from this formation shows that these sandstones are classified as litharenite, feldspathic litharenite, sublitharenite, feldspathic wacke, and lithic wacke, which are partially calcareous. Preserved diagenetic processes were visible on the petrographic analysis including cementation, replacement, dolomitization, compaction, and dissolution. The provenance of these sandstones is dominated by granitic rocks initiated from tectonic setting of rifted continental margin, transported toward southeast.

Keywords: petrography, sandstone, diagenesis, provenance

Sari

Studi ini difokuskan pada asal dan proses diagenesis yang telah berpengaruh terhadap batupasir Formasi Lati yang tersingkap di daerah Berau, Provinsi Kalimantan Timur. Pengujian petrografis terhadap dua puluh dua percontoh yang diambil dari formasi ini memperlihatkan bahwa jenis batupasir yang dijumpai terdiri atas litarenit, litarenitfelspatis, sublitarenit, wakefelspatis, dan wakelitik, yang beberapa bersifat gampingan. Proses diagenesis yang terawetkan dan teramati pada pengujian petrografis meliputi penyemenan, penggantian, pendolomitan, pemampatan, peretakan, dan pelarutan. Sumber dikuasai oleh batuan granitan yang berasal dari lingkungan tektonik tepian benua dan terangkut ke arah tenggara.

Kata kunci: *petrografi, batupasir, diagenesis, asal*

Introduction

Tarakan Basin located in East Kalimantan (Akuanbatin and Rosandi, 1983) is divided into four subbasins, namely Tarakan, Tidung, Berau, and Muara Subbasins (Tossin and Kadir, 1996; Figure 1). The area of research is in Berau Subbasin. One of the formations in the Berau Subbasin is Lati Formation. Stratigraphy of this formation is obtained from the results of detailed stratigraphic measurements at three locations, namely Lati, Binungan, and Sambarata sections (Rachmansyah *et al*., 2003), added and supported by a discussion focused on the sedimentologic processes (Maryanto *et al*., 2005) and their coal content (Maryanto, 2011).

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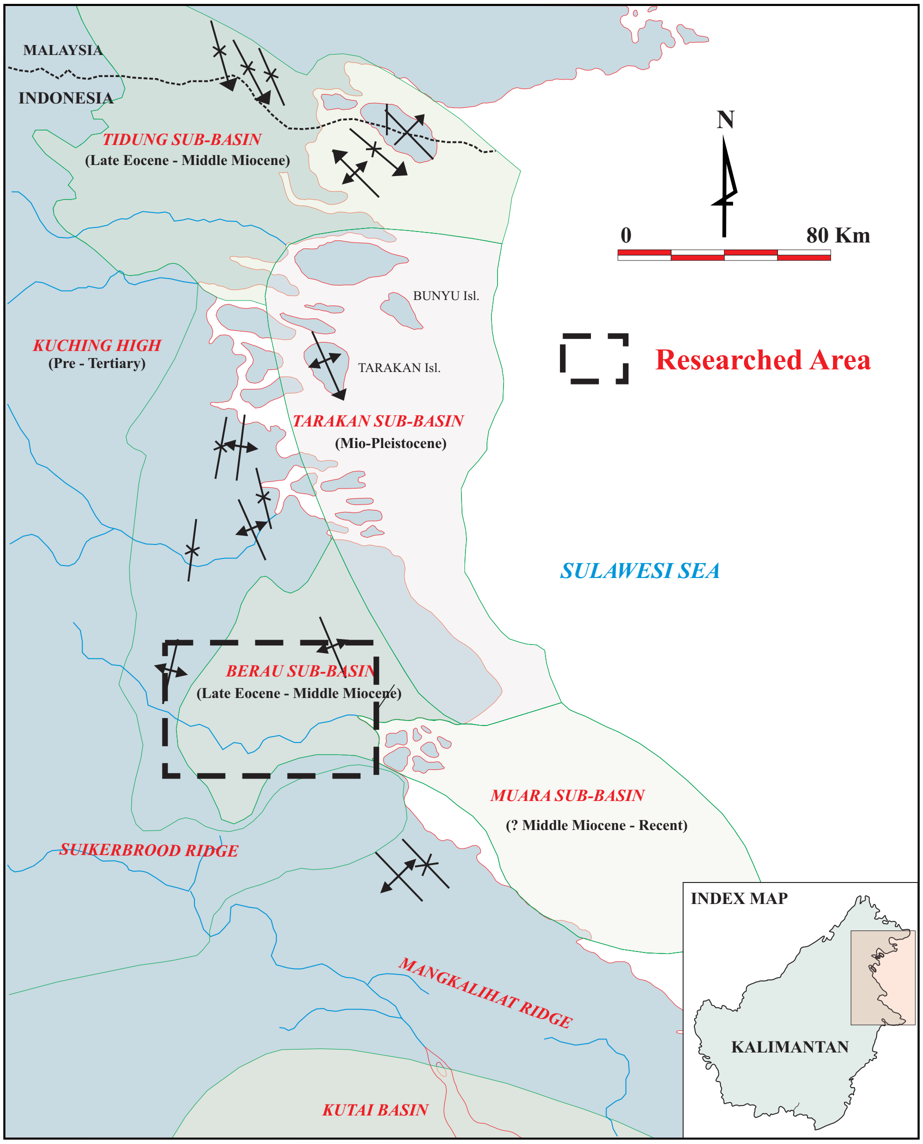

Figure 1. Locality map of Tarakan Basin area, divided into four subbasins, namely Tidung, Tarakan, Berau, and Muara Basins (Tossin and Kadir, 1996).

The research method is to analyze sandstone petrographically focused on the amount and type of their main components as well as the appearance of sandstone diagenetic process under a polarization microscope. This research was conducted to find out the petrographic characteristics of the sandstones forming Lati Formation, including the diagenetic process and estimation of tectonic environment of their source rocks.

The research locality is situated in part of the Berau Subbasin, bounded by coordinates 117^0 10' - 117^0 40' E and 02^0 00' - 02^0 20' N, administratively falling under the Berau Regency, East Kalimantan Province, Indonesia. The location of the stratigraphic sections are at Binungan, Lati, and Sambarata (Figure 2).

Stratigraphy

Stratigraphy of the researched area that has been mapped to a ternary scale 1: 250.000 by

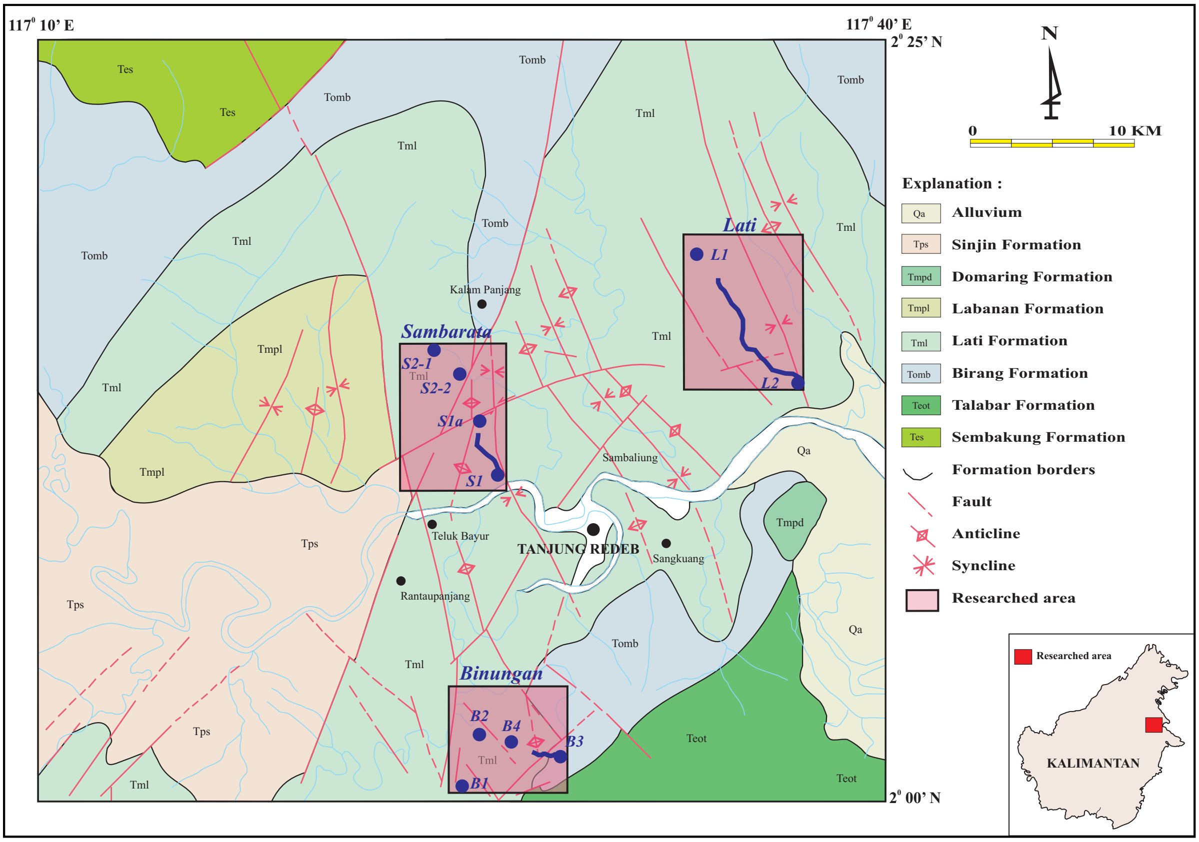

Figure 2. Geologic map of Berau area, East Kalimantan (Situmorang and Burhan, 1995) and the location of detailed stratigraphic measurements in Lati, Binungan, and Sambarata.

Situmorang and Burhan (1995), was sequentially started from the old to the young, consisting of the Sembakung, Talabar, Birang, Lati, Labanan, Domaring, and Sinjin Formations, as well as alluvium, recpestively.

The Sembakung Formation unconformably overlying Late Cretaceous rocks, consists of calcareous siliciclastic rocks with shallow marine depositional environment of the Eocene age. The Talabar Formation is composed of carbonate and fine siliciclastic rocks deposited in fluviatil to shallow marine environment at the Eocene-Oligocene age. The Birang Formation unconformably overlying the Talabar Formation and consisting of carbonate and siliciclastic rocks and tuff, shows a depositional environment of shallow to deep marine of Oligo-Miocene age. The Lati Formation comprising fine siliciclastic rocks with coal intercalations was deposited at delta, estuarine, and shallow marine at Early to Middle Miocene, with a thickness of about 800 m. It conformably overlies the Birang Formation. Then, the Late Miocene to Pliocene Labanan Formation making up of siliciclastic rocks with coal intercalations unconformably overlies the Lati Formation. The rock unit was deposited in a fluvial area. In turn, the Labanan Formation interfinger with the Domaring Formation, composed of carbonate rocks with lignite intercalations. Moreover, the Sinjin Formation conformably overlying the Labanan and Domaring Formations, is composed of volcaniclastic rocks of the Pliocene age. Finally, the youngest unit, Alluvium, unconformably overlies the rock units formed.

The investigated unit, Lati Formation was deposited in the Middle Miocene delta. The top of this formation contains a number of coal intercalations (Anonym, 1983; 1988). Detailed stratigraphy of the Lati Formation refers to the research results of Rachmansjah *et al.* (2003) and Maryanto *et al.* (2005).

Stratigraphic succession in Lati Section begins with the presence of calcareous mudstone with sandstone intercalations (Figure 3). It represents prodelta fasies, evolving into a massive sandstone unit (Figure 4), sometimes with mudstone intercalations which represents the delta front facies. This delta front facies was immediately changed by delta plain facies, forming the upper part of the formation, comprising mudstone and claystone with occasionally calcareous sandstone, coaly shale, and coal intercalations (Maryanto, 2011).

Stratigraphic succession in Binungan Section starts with the presence of calcareous claystone, calcareous mudstone, with sandstone, calcareous sandstone, and limestone intercalations. The middle part of the succession partially consists of carbonaceous and calcareous mudstone with sandstone intercalations that soon evolved into sandstone bedding (Figure 5) with a little mudstone intercalations. The upper part of the formation consists of mudstone, which sometimes develop into coaly shale and claystone with sandstone and coal intercalations.

Figure 3. Photograph of fine- grained sandstones with bands and concretions of siderite constituent in the middle part of Lati Formation. Lati traverse 2 (Rachmansjah *et al*., 2003).

Figure 4. Photograph of a trough cross-bedded structure at very fine- grained sandstone in the middle part of Lati Formation. Lati traverse 2 (Rachmansjah *et al*., 2003).

Figure 5. Photograph of sandstone with claystone intercalations at the upper part of the Lati Formation affected by tectonics (micro fault). Binungan traverse 1 (Rachmansjah *et al*., 2003).

Stratigraphic succession in Sambarata Section was initiated by the presence of mudstone, claystone, and sandstone (Figure 6) with coaly shale and coal intercalations. The succession repeated several times, leading to the presence of more coal intercalations at the upper part of the formation.

Figure 6. Photograph of parallel and cross-lamination structures on the upper part of the Lati Formation. Sambarata traverse 1 (Rachmansjah *et al*., 2003).

Petrography

A petrographic analysis was carried out against twenty-two sandstone samples taken from the three sections mentioned above. Using the sandstone classification by Pettijohn (1975), the sandstone constituent of the Lati Formation is divided into several types, including litharenite, sublitharenite, lithic greywacke, and feldspathic greywacke (Table 1). In some sandstone samples, carbonate mineral exhibits a fair amount, so the rocks become calcareous.

General Features

The sandstone thin sections are usually colourless to brownish, massive, coarse to fine clastic texture with moderately to poorly sorted and grain supported. The grain shape is angular to rounded with relationships between grains of type floating, point, long, concave-convex, and very rarely sutured. The component consists of monocrystalline quartz 16 - 72%, polycrystalline quartz 2 - 12%, potassium feldspar 0 - 5%, plagioclase 1- 8%, volcanic rock fragments 0 - 2%, sedimentary rock fragments

Table 1. The Resume of the Petrographic Testing of Sandstones from Lati Formation in Berau Area

Nu.	Sample Code	Qm	Qp	Kf	Pl	Lv	Ls	Lm	Lg	Ot	Mt	Cl	Ch	Si	Io	Ca	Po	RN
1.	L2-01	26.0	6.5	4.5	1.0	0.0	2.0	0.0	2.0	0.0	51.0	1.0	0.0	0.0	1.0	0.0	0.5	FG
2.	L2-03	33.0	7.0	1.0	8.0	0.0	10.0	4.0	4.0	3.5	16.0	2.0	0.5	1.0	6.0	0.0	2.0	LG
3.	L2-07	24.0	3.0	0.0	4.0	0.0	10.0	0.0	1.0	8.0	54.0	0.0	0.0	0.0	4.0	0.0	0.0	LG
4.	L2-08	32.0	3.0	0.0	6.0	0.0	4.5	0.0	0.5	2.0	39.0	4.0	1.5	3.5	4.0	0.0	1.0	FG
5.	L2-09	51.0	3.0	0.5	6.0	1.0	8.0	2.0	2.0	0.0	0.0	4.0	0.0	6.0	2.5	0.0	14.0	SL
6.	L2-10	72.0	6.0	0.0	2.0	0.0	12.0	2.0	2.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	SL
7.	L2-12	34.0	4.0	0.0	7.0	0.0	2.0	0.0	2.0	1.0	40.0	2.0	2.0	3.0	1.0	0.0	2.0	FG
8.	L2-15	48.0	12.0	0.5	2.5	0.0	8.0	2.0	1.0	2.5	21.0	2.0	1.5	5.5	2.5	0.0	4.5	LG
9.	L2-17	46.0	6.0	1.0	6.0	0.0	11.0	3.0	5.0	1.0	0.0	4.0	1.5	10.0	2.5	0.0	3.0	LA
10.	B1-04	47.0	3.0	0.0	2.0	0.0	22.0	2.0	2.0	2.0	0.0	7.0	2.0	2.5	4.5	3.0	1.0	LA
11.	B1-07	44.0	6.0	1.0	4.0	2.0	21.0	6.0	2.0	0.5	0.0	5.0	0.5	3.0	3.5	0.0	4.5	LA
12.	B2-11	58.0	12.0	0.0	4.0	0.0	15.0	2.0	6.0	0.0	0.0	0.0	0.0	1.0	2.0	0.0	0.0	SL
13.	B2-15	48.0	9.0	0.0	3.0	2.0	25.0	4.0	6.0	0.0	0.0	0.0	0.0	1.0	2.0	0.0	0.0	LA
14.	B2-17	42.0	6.0	8.0	2.0	0.0	14.0	2.0	9.0	0.0	0.0	3.0	0.0	2.0	7.0	0.0	6.0	LA
15.	B2-19	42.0	5.0	1.0	3.0	0.0	14.0	2.0	2.0	3.0	0.0	6.0	0.0	3.0	3.0	16.0	1.0	LA
16.	B3-06	43.0	12.0	0.0	6.0	0.0	4.0	2.0	8.0	0.0	0.0	4.0	0.0	0.0	1.0	14.0	0.0	SL
17.	B3-07	43.0	6.0	4.0	2.0	2.0	12.0	3.0	5.0	0.5	0.0	4.0	0.5	1.0	1.0	14.0	2.0	LA
18.	B3-08	38.0	6.0	3.0	3.0	0.0	8.0	2.0	2.0	0.0	35.0	0.0	0.0	0.0	4.0	0.0	0.0	LG
19.	B3-10	39.0	6.0	5.0	3.0	2.0	16.0	3.0	2.0	1.5	0.0	4.0	0.5	1.0	3.0	12.0	2.0	LA
20.	B3-20	42.0	4.0	4.0	2.0	1.0	22.0	4.0	2.0	1.0	0.0	6.0	0.0	1.0	4.0	4.0	3.0	LA
21.	S1-09	36.0	7.0	3.0	2.0	1.0	19.0	6.0	3.0	2.0	0.0	8.0	1.0	2.0	4.0	4.0	2.0	LA
22.	S1-02	16.0	2.0	2.0	1.5	0.0	4.0	0.5	0.0	8.0	58.0	0.0	0.0	0.0	2.0	6.0	0.0	LG

Explanation:

Components:

Qm : Mono quartz   Pl : Plagioclase   Cl : Clay   Mt : Matrix   Si : Silica   Ca : Carbonates
Qp : Poly quartz   Lv : Volcanic rf.   Ch : Chlorite   Po : Porosity   RN: Rock name   Io : Iron oxides
Kf : Potasium feldspar   Ls : Sedimentary rf.   Lm: Metamorphic rf.   Lg : Granitic rf.

Rock Name:

FG : Feldspathic greywacke   LA : Litharenite
LG : Lithic greywacke   SL : Sublitharenite

2 - 25%, metamorphic rock fragments 2 - 6%, granitic rock fragments 0 - 9%, other minerals 0 - 8%, matrix 0 - 58%, authigenic clay 0 - 8%, chlorite 0 - 2%, silica cement 0-10%, iron oxide 1 - 6%, and carbonate cement 0-16%. Rock porosity 2 - 14% is present in the form of an interparticle type.

Quartz as the main component of rock is dominated by monocrystallin type showing an undulating extinction and coarser in size (Figure 7). Besides that, more than three polycrystalline types are also present. Sometimes, they are still present in the granitic rock fragments. In some samples, quartz, especially monocrystalline quartz, exists as an overgrowth one, which is sometimes ambiguous with silica cement (secondary quartz).

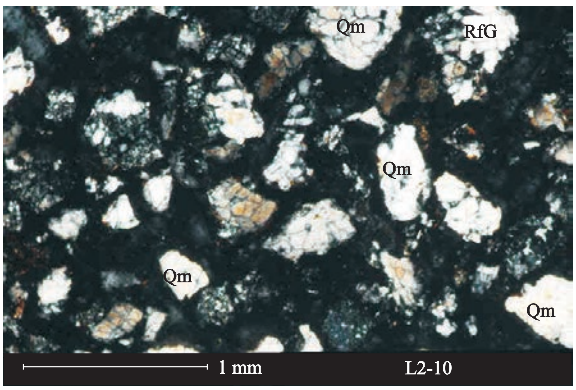

Figure 7. Photomicrograph of sublitharenite sandstone dominated by monocrystalline quartz (Qm), granitic rock fragment (RfG), with no matrix, and very rare cementing material, so be prepared with a mounting system. Sample code L2-10.

Feldspar present rarely occurs as potassium feldspar and plagioclase. Potassium feldspar is made up of orthoclase, sporadically spread. Plagioclase, especially a kind of oligoclase until andesine, denoting a twinning and sometimes has started to show zoning in their composition. Through the zoning composition field, a small part of plagioclase starts to be altered in to a clay mineral. This alteration process took place within potassium feldspar.

Rock fragments are present in a fair amount in the sandstones tested. Rock fragments are mostly composed of argillaceous sediments, both on coarse (Figure 8), and fine (Figure 9) sandstones with minor very fine- grained sandstone, and very rare limestone fragments. Most of sedimentary rock fragments

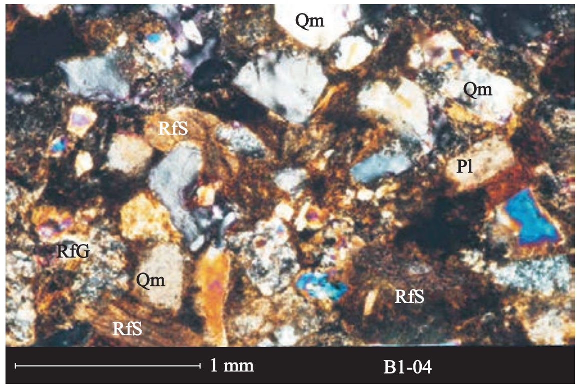

Figure 8. Photomicrograph of litharenite sandstone showing several grains of monocrystalline quartz (Qm), granitic rock fragment (RfG), and argillaceous sedimentary rock fragments (RfS). Sample code B1-04.

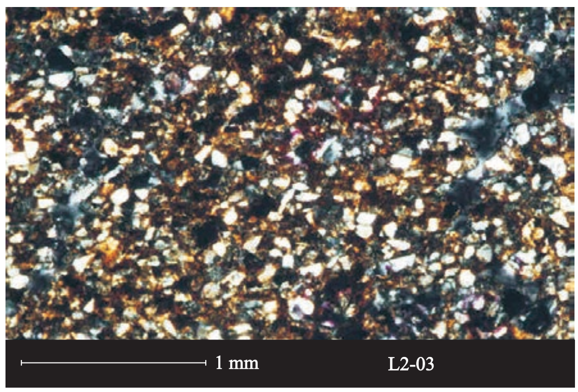

Figure 9. Photomicrograph of lithic wacke sandstone developing within fine- grained size. Sample code L2-03.

have been weathered and altered. Metamorphic rock fragments are present, rarely composed of gneiss, phyllite, and granitic gneiss. The granitic rock fragments are found in some coarser size.

More fine-grained components consisting of opaque mineral such as carbon and magnetite are rarely recognized. In addition, glauconite, hornblende, and biotite are still detected.

A rock matrix can be seen in fine sandstone, whereas in coarser sandstone it is not present (Figure 10). The rock matrix is generally found as clay minerals with very fine- grained quartz and feldspar.

Secondary minerals and cementing grains are present in the Lati sandstones consisting of authigenic clays, silica, chlorite, iron oxides, and carbonates. Authigenic clays, in general, are con-

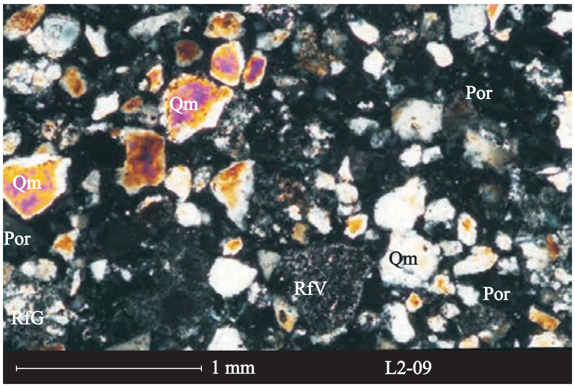

Figure 10. Photomicrograph of moderately sorted sublitharenite sandstone showing several grains of monocrystalline quartz (Qm), granitic rock fragment (RfG), volcanic rock fragment (RfV), and interparticle pores (Por). Sample code L2-09.

centrated as a result of alteration and weathering of rock fragments, as well as plagioclase, primarily through the mineral zoning areas. Clay, minerals actually also include montmorilonitic clay, chloritic clay, and sericitic clay. Chlorite is very rarely present, fibrously very fine crystals instead of rock fragments. Microcrystalline or very fine irregular anhedral quartz crystals are present mostly as the result of overgrowth quartz grains and also a result of silicification of clay mineral matrix. Iron oxides, including siderite, are present as the binder between grain patterns and they have irregular distribution. Carbonate minerals are mainly preserved as drussy mosaic anhedral calcite crystals, which formed at meteoric phreatic diagenetic environment. This calcite was evenly distributed as calcite grain cementing material on some samples, especially in the middle part of the Lati Formation.

Diagenetic Process Records

Diagenetic process recorded on preserved sandstones of the Lati Formation includes cementing, replacement, dolomitization, compaction, fracturing, and dissolution.

Cement present in the Lati sandstones is generally iron oxides, dull brown to black colour. These iron oxides are irregular and dispersed unevenly, and sometimes concentrated somewhere as the result of total replacement of mafic mineral. Silica or quartz cement is generally present as the result of quartz grain overgrowth, both as monocrystalline or polycrystalline quartz. Orthosparit calcite is the main cement in calcareous sandstones, and when found, their binding is perfect enough among the existing grains (Figure 11). Orthosparit calcite generally appears as drussy mosaic anhedral fine to medium crystals, while the other cement structure no more preserved.

Some grains of plagioclase and potassium feldspar seem to be experiencing replacement into clay minerals including sericite. Plagioclase replacement started from the mineral zonation with low intensity replacement. Chlorite present as groups of very fine crystalls, is presumed as a totally replacement of mafic minerals such as hornblende and mica. Authigenic clay minerals and chlorite are also present as a substitute of volcanic rock fragments and sedimentary rock fragments. Either chlorite minerals or clay minerals in sandstones of the Lati Formation were preserved as the result of replacing course, and can not function as grain cementing material.

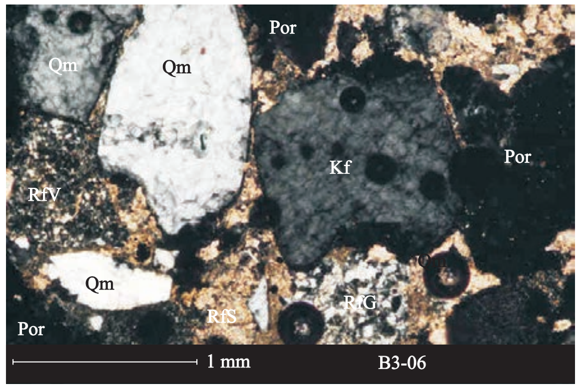

Figure 11. Photomicrograph of orthosparite calcite as cementing material on calcareous sublitharenite sandstone shows several grains of monocrystalline quartz (Qm), pottassium feldspar (Kf), granitic rock fragment (RfG), volcanic rock fragment (RfV), and interparticle pores (Por). Sample code B3-06.

Dolomitization is recorded in some parts of orthosparite. Dolomite crystals are found in very fine size, mosaic granular structure, and concentrated in the grain margins. It is estimated that the dolomite crystals came from early stage of orthosparite after rock deposition from marine environment, and they have been very rarely preserved.

Compaction process is characterized by concave-convex grain contact, or even on some samples having a suture grain contact. The concave-convex contact mostly occurs on an argillaceous rock fragment related with quartz (Figure 12). Although already showing the sutured contact, the appearance pattern of stylolite has not been present in the tested sandstones. Thus, it can be said that the influence of tectonics or faulting had happened at these sandstones. The compaction process generally greatly affects the reduction in value of rock porosities.

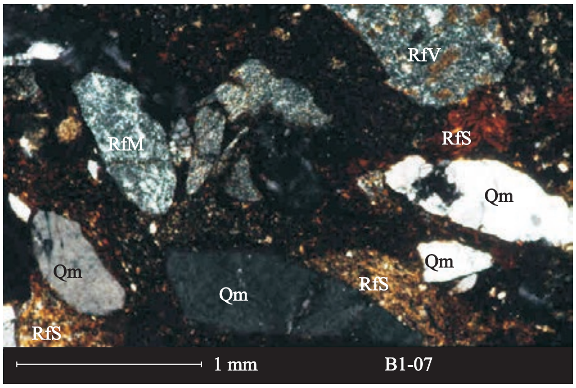

Figure 12. Photomicrograph of litharenite sandstone composed of several monocrystalline quartz (Qm), metamorphic rock fragments (RfM), volcanic rock fragments (RfV), and sedimentary rock fragments (RfS). This rock shows a concave-convex grain contact due to compaction. Sample code B1-07.

Although the fracturing features under a microscope polarization were not properly recorded, the process results can be seen directly in the field (Figure 5). Fracturing process is made up of tectonic fissures and cracks on the surface due to vegetation activities.

Rock porosities are still present in some samples, especially free matrix sandstones. Rock porosity types mostly widely encountered are interparticle and irregular vuggy types. The irregular vuggy type was formed as the result of postdeposition dissolution process. The value of interparticle in general has been reduced, or completely disappeared due to cementation and compaction. Some fissure fore types due to the shear jointing process are found rarely.

Rock Provenance

Identification of provenance in sandstone is based on a proportion of the number of main petrographic component including quartz, feldspar, and rock fragments. Counted data required include type and quantity of quartz - feldspar - rock fragments; monocrystalline quartz – feldspar – total rock fragments; polycrystalline quartz - volcanic rock fragments - sedimentary rock fragments; and metamorphic rock fragments - volcanic rock fragments - sedimentary rock fragments. Identification of provenance using the characters of quartz mineral (Tucker, 2001: Boggs, 1992) at the deep marine sandstone (Yerino and Maynard, 1984, in Boggs, 2001) is not performed on this paper. Table 2 shows the comparison of the percentage of each rock component.

The first plotting diagram is to determinate the rock name performed on the Q-F-L triangle diagram according to Pettijohn (1975). The plotting result on this diagram shows that the types of the sandstones are litharenite, sublitharenite, lithic greywacke, and feldspathic greywacke. With respect to the limitation of the number of samples that exists, then sandstone types of lithic greywacke and feldspathic greywacke are still also used for the next plotting (Figure 13).

The second plotting was performed using Q-F-L and Qm-F-Lt triangle diagrams according to Dickinson *et al.* (1983). It is useful for determining the regional tectonic environment of source rocks (provenance). Based on the results of the plotting in the Q-F-L diagram, it appears that the provenance of Lati Formation is the recycled orogenic area. A more detailed determination was carried out by plotting it in the Qm-F-Lt diagram, which shows that the provenance of Lati Formation was quartzose recycled environment up to transition recycled environment (Figure 14).

The third plotting was carried out on the Qp-Lvm-Lsm and Lm-Lv-Ls diagrams according to Ingersoll and Suczek (1979) which also determined the regional tectonic of source rock environment. Based on diagram of Qp-Lvm-Lsm, it can be seen that the source of Lati Formation is the suture belt to the rifted continental margins. Moreover, plotting on Lm-Lv-Ls diagram more clearly show that the source rock composing the Lati Formation was initially from the rifted continental margin (Figure 15).

Discussion

The sandstone constituents of Lati Formation found in the Berau, East Kalimantan, generally have medium to fine grain size. Ideally, studying the sandstone provenance requires coarser grain

Table 2. Percentage Components of Sandstones from Lati Formation in Berau Area

No.	Sample Code	Q	F	L	Qm	F	Lt	Lv	Ls	Lm	Qp	Lvm	Lsm
1.	L2-01	82.1	13.1	4.8	61.9	13.1	25.0	0.0	100.0	0.0	81.0	0.0	19.0
2.	L2-03	65.7	13.4	20.9	49.3	13.4	37.3	0.0	71.4	28.6	52.4	0.0	47.6
3.	L2-07	66.7	9.5	23.8	57.1	9.5	33.3	0.0	100.0	0.0	28.6	0.0	71.4
4.	L2-08	77.2	13.0	9.8	69.6	13.0	17.4	0.0	100.0	0.0	43.8	0.0	56.3
5.	L2-09	76.2	8.8	15.0	69.4	8.8	21.8	9.1	72.7	18.2	15.5	3.1	24.9
6.	L2-10	83.3	2.1	14.6	75.0	2.1	22.9	0.0	85.7	14.3	40.0	0.0	60.0
7.	L2-12	81.6	14.3	4.1	69.4	14.3	16.3	0.0	100.0	0.0	75.0	0.0	25.0
8.	L2-15	82.4	4.1	13.5	64.9	4.1	31.1	0.0	80.0	20.0	61.9	0.0	38.1
9.	L2-17	73.1	9.0	17.9	59.0	9.0	32.1	0.0	78.6	21.4	50.0	0.0	50.0
10.	B1-04	66.7	2.6	30.8	60.3	2.6	37.2	0.0	91.7	8.3	18.5	0.0	81.5
11.	B1-07	60.5	5.8	33.7	51.2	5.8	43.0	6.9	72.4	20.7	15.5	3.9	40.6
12.	B2-11	78.4	4.1	17.5	59.8	4.1	36.1	0.0	88.2	11.8	54.5	0.0	45.5
13.	B2-15	64.9	3.1	32.0	49.5	3.1	47.4	6.5	80.6	12.9	35.7	4.8	59.5
14.	B2-17	68.7	12.0	19.3	50.6	12.0	37.3	0.0	87.5	12.5	36.1	0.0	33.7
15.	B2-19	71.0	5.8	23.2	60.9	5.8	33.3	0.0	87.5	12.5	33.3	0.0	66.7
16.	B3-06	84.0	8.0	8.0	57.3	8.0	34.7	0.0	66.7	33.3	83.3	0.0	16.7
17.	B3-07	70.1	7.8	22.1	55.8	7.8	36.4	11.8	70.6	17.6	25.8	4.7	28.1
18.	B3-08	74.2	9.7	16.1	61.3	9.7	29.0	0.0	80.0	20.0	50.0	0.0	50.0
19.	B3-10	61.8	10.5	27.6	51.3	10.5	38.2	9.5	76.2	14.3	30.8	7.7	61.5
20.	B3-20	59.3	7.4	33.3	51.9	7.4	40.7	3.7	81.5	14.8	20.7	3.4	75.9
21.	S1-09	59.7	6.5	33.8	46.8	6.5	46.8	3.8	73.1	23.1	33.3	3.3	63.3
22.	S1a-02	69.2	13.5	17.3	61.5	13.5	25.0	0.0	88.9	11.1	33.3	0.0	66.7

size, however, it was absolutely not found in the researched area.

The diagenetic processes affecting the sandstones of Lati Formation have taken place soon after the rock sedimentation until they cropped out on the surface today. The diagenetic process took place concurrently or followed another diagenetic process (Figure 16). In such circumstances, there is a certain linkage among each other.

Petrographic analyses results show that the sandstone was deposited at a deltaic environment (Maryanto, 2011). This environment only preserved a small amounts of the marine cement, although it is possible that the cement was initially quite a lot. Its cementing process continued on marine burial diagenesis (Melim *et al*., 2001; Ramadan *et al*., 2004). However, the cements from both environments have been broken and replaced by neomorphism and cementation processes that occured in the meteoric phreatic by the time the rocks cropped out. The other cementing materials were present in the form of quartz cement and iron oxides, both of which began to be present during burial diagenesis. The quartz cement formed on the burial environment up to early meteoric, coincided with the quartz overgrowth. In contrast, iron oxides were still present in the meteoric environment together with authigenic clay minerals.

The burial phase of Lati Formation resulted in the well compaction process, and ended at the time the rock cropped out. The process of alteration and replacement of sandstone forming grains occurred in this burial diagenesis. Additionally, in this burial phase also occurs a low non-fabric selective dolomitization process. Although it is indistinct, fracturing due to tectonic processes, followed by uplifting of

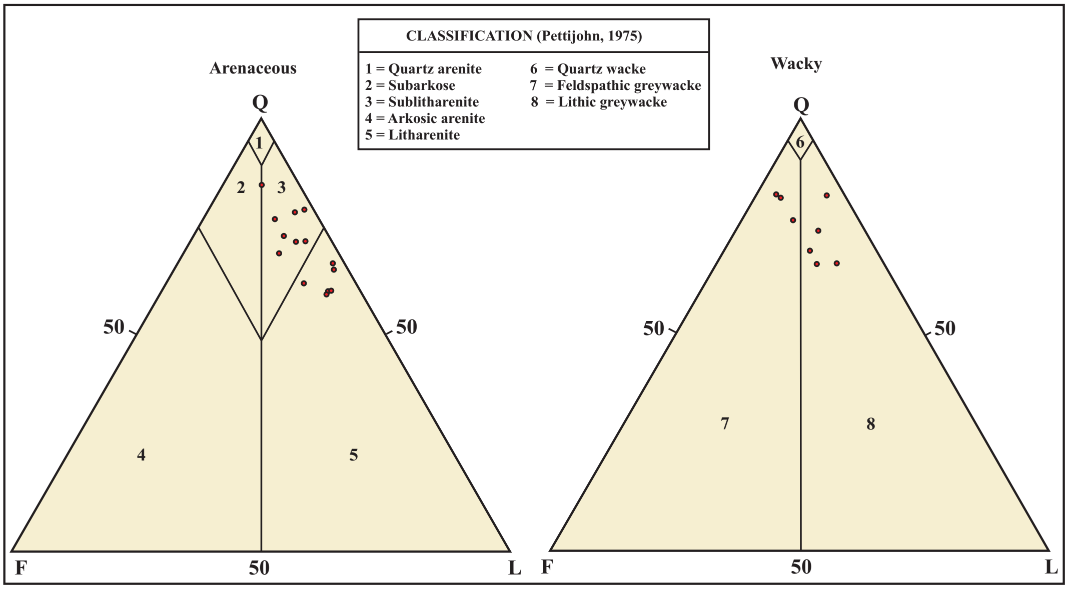

Figure 13. Sandstone classification according to the triangle diagrams of Pettijohn (1975) of the Lati Formation in Berau area, East Kalimantan, Indonesia.

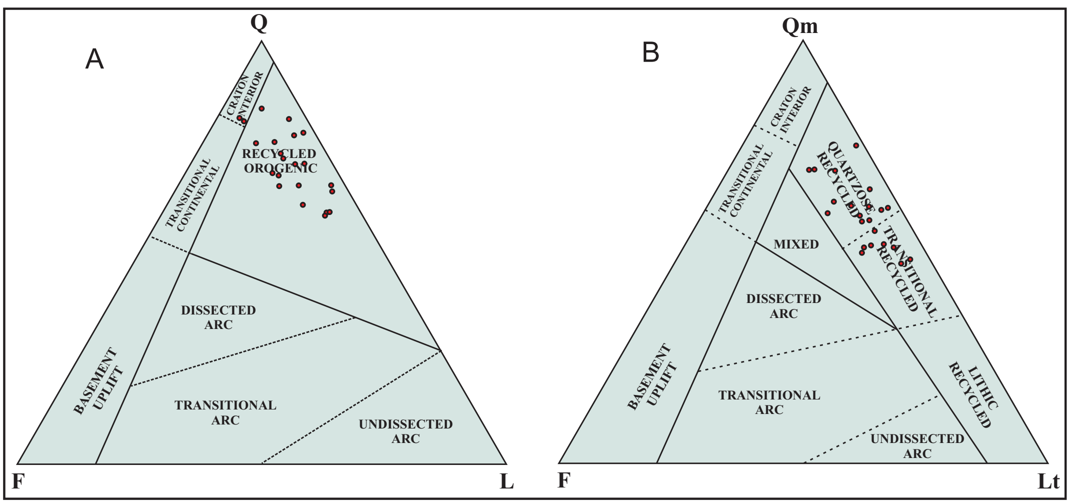

Figure 14. Tectonic environment of the sandstone source rock (Dickinson *et al.*, 1983) of the Lati Formation in Berau area, East Kalimantan, Indonesia.

formation, can still be seen in some samples. Authigenic clay minerals are present in some samples filling the fractures due to burial process (Tucker and Wright, 1990), and sometimes occur and concentrated in the dissolution pores.

The end results of the dissolution process after uplifting at a meteoric zone is the formation of dissolution vuggy pores (Moore, 1997). The diagenetic processes that have influenced the Lati Formation, caused the pores of rocks developed in accordance with the order of the diagenetic process. Rock porosities were commenced with a lot of interparticle type porosity. It is identified by the limited cementing material between grains that originated in the marine and burial environments, thus forming a type of an interparticle porosity. Vuggy type pores ensue, as well as several fracture type porosity emanating from the shear fractures due to tectonics. Some kinds

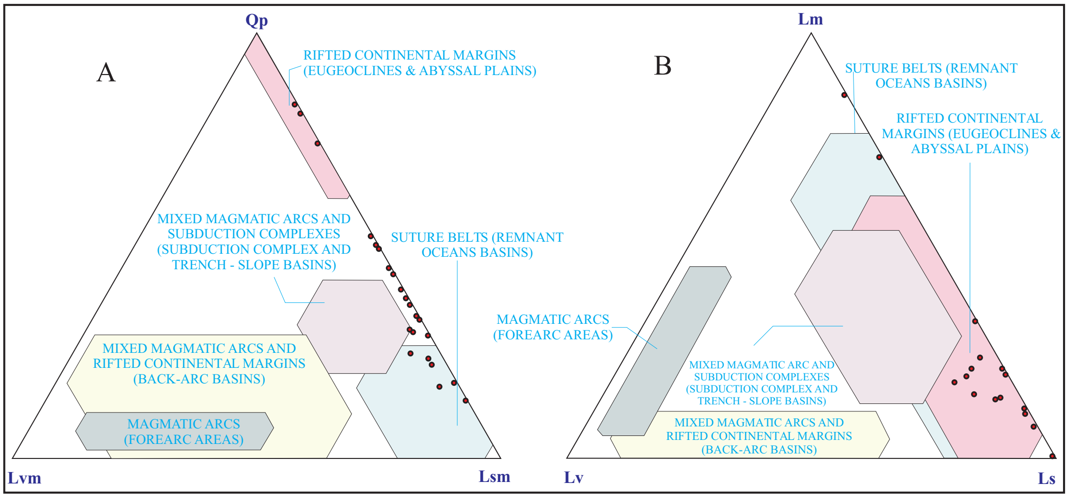

Figure 15. Plotting of sandstone components in the triangle diagrams according to Ingersoll and Suczek (1979) showing the provenance of the Lati sandstone, Berau area, East Kalimantan.

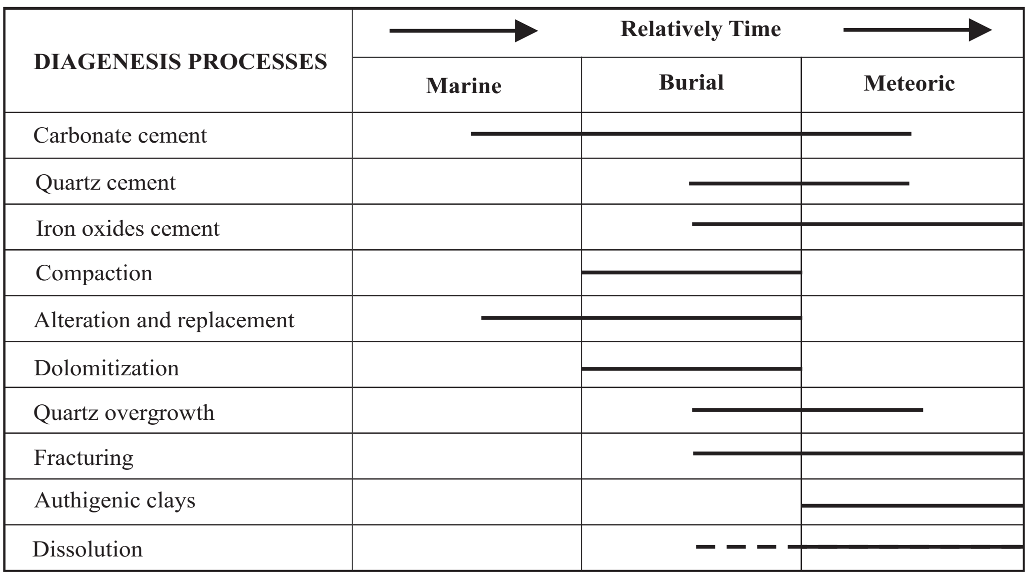

Figure 16. Historical diagram of the diagenesis processes in relation to relative time on the Lati sandstones around Berau, East Kalimantan, Indonesia.

of the porosities have been covered by the meteoric phreatic cement.

The provenance of the Lati Formation at Berau area, East Kalimantan, generally comes from recycled orogenic environment, in particular on the quartz-rich region, which is presumed to be a granitic rock. The granitic rock dominated the source rocks, which regionally are margin of southeastern part of Eurasian content. It is in accordance with the regional geology which in general, the researced areas were in the southeastern part of the Eurasian Continent (Hall and Wilson, 2000; Hall, 2001). Thus the position of the depositional basin was in the south to the east.

Paleocurrent data of the Lati Formation show the southern to eastern directions (Maryanto, 2011), characterizing the distributary channel system, which is part of a deltaic depositional system (Fisher *et al.*, 1976; Marks *et al.*, 1982). The source rocks ware transported into the main basin located in the south to east. The relative position of the ridge and basin did not changed during the Tertiary time, even until today.

Conclusions

The Lati sandstones are made up of litharenite, felspathic litharenite, sublitharenite, feldspathic wacke lithic, that some are calcareous. Diagenetic process observed under a microscope polarization includes cementation, replacement, dolomitization, compaction, fracturing, and dissolution. The porosity value of the sandstones decreased due to the diagenetic process.

Source rocks composing the Lati Formation were transported to the main basin located in the southern to eastern areas. Those source rocks are dominated by granitics, as well as some sediments, metamorphics, and very rare volcanics, derived from recycled orogenic regionally was situated in a rifted continental margin.

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