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Provenance Analysis of The Rampong Formation Sandstone in The Ketukah Area, Gayo Lues, Aceh

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Abstract

The research location is in Ketukah, Gayo Lues Aceh, which is composed of the Late Oligocene to Early Miocene Rampong Formation. Lithology includes sandstones, conglomerates, and mudstones. The study aims to determine the origin of the sandstones in the Rampong Formation. Provenance studies are beneficial in providing information for oil and gas exploration. The analysis is critical for understanding the sediment transport channel, the overall depositional pattern of the basin, and predicting the location of sand bodies in the basin. Because the Rampong Formation is located in the North Sumatra Basin, the availability of provenance information is useful in efforts to search for oil and gas potential in the future. In this research, we restrict the study to the provenance, which includes the tectonic setting, origin rock, and paleoclimate where these sandstones originate. The methods are geological mapping and petrographic analysis. In petrographic analysis, we use JMicrovision to calculate mineral composition. The results showed that the sandstones of the Rampong Formation are arenite sandstones, especially sub-arkosic and sub-lith arenite. They originate from a tectonic setting known as a recycled orogen, related to the subduction of Eurasia and the Indo-Australian plates. The sandstones were formed from granite that had undergone low metamorphism in the Late Cretaceous to the Eocene period. In addition, the paleoclimate is humid.

Introduction

The research location is in Ketukah Village, Blangjerango District, Gayo Lues, Aceh, with coordinates 4º2'00" and 4º4'30" N and 97º6'30" and 97º9'30" E. The area comprises the Rampong Formation (Tlr) consisting of sandstone, conglomerate, and mudstone [1]. The location and geological map are attached in Appendix 1. This location is included in the Barisan Zone, where there are mountains to the northwest of Sumatra Island and lower mountains to the west of the east coast. While in the east, it is dominated by a vast alluvial plain near the Malacca Strait [2].

Provenance is the study of determining the origin of sedimentary rocks, specifically sandstone. It is essential for sandstone because its constituents provide necessary evidence of source rock

[3]. There are methods to determine the provenance, one of which is petrographic analysis. Petrographic methods analyze the composition and texture of sedimentary rocks. Tectonic settings affect the composition and texture of sedimentary rocks. Because the texture and mineral composition are sometimes not visible to the eye, petrographic observation using a microscope is an advantageous method. The concept classifies the various compositions of sandstones into three provenance types: continental block, recycled orogen, and magmatic arc [4].

Provenance studies are useful in giving information for oil and gas development since the research is critical for understanding sediment transport channels, the depositional pattern of the basin, and the interpretation of the sand bodies' location in the basin [5]. Because the Rampong Formation is located in the North Sumatra Basin, the availability of provenance information is important in future efforts to find oil and gas potential. In this research, we focus on the Rampong Formation sandstone. The origin of the Rampong sandstone has not been studied, so the provenance study was conducted to determine the tectonic setting, the origin rock, and the paleoclimate of the source area. On the other hand, the current research has been carried out on the Neogene Seulimeum Formation, Aceh, Indonesia, where the sandstone comes from recycled orogenic tectonic settings. It is comprised mainly of the Woyla Group, and there are some contributions from Bentaro volcanic and Paleogene to early Neogene sediments [6].

Theory

a. Geological setting

Sumatra lies along the southwestern margin of the SE Asian continent (Sundaland) beneath which the Indian Ocean Plate is currently being subducted at a rate of about 7 cm per year in the Sunda Trench [7]. Subduction causes the formation of back-arc basins along the island of Sumatra, i.e. the North Sumatra Basin, Central Sumatra Basin, and South Sumatra Basin as depicted in Figure 1. These basins are filled with Tertiary sedimentary rocks, where in the Miocene age sandstone and siltstone were deposited in the Rampong Formation [8].

b. Sedimentary rock

Sedimentary rock comprises approximately 75% of the total rock composition on Earth's surface. It is a compound of minerals and rock fragments derived from the erosion process of diverse rock types, then deposited and lithified [3][9].

Sandstone is generally composed of terrigenous material. Older rocks are weathered and eroded from land, then deposited to form sedimentary rocks. Typically, sandstone is composed of stable minerals, such as quartz, feldspar, clay, and a lithic fragment. The mineral abundance depends on the mechanical and chemical processes of the minerals, as well as the availability of minerals in the origin rock [9].

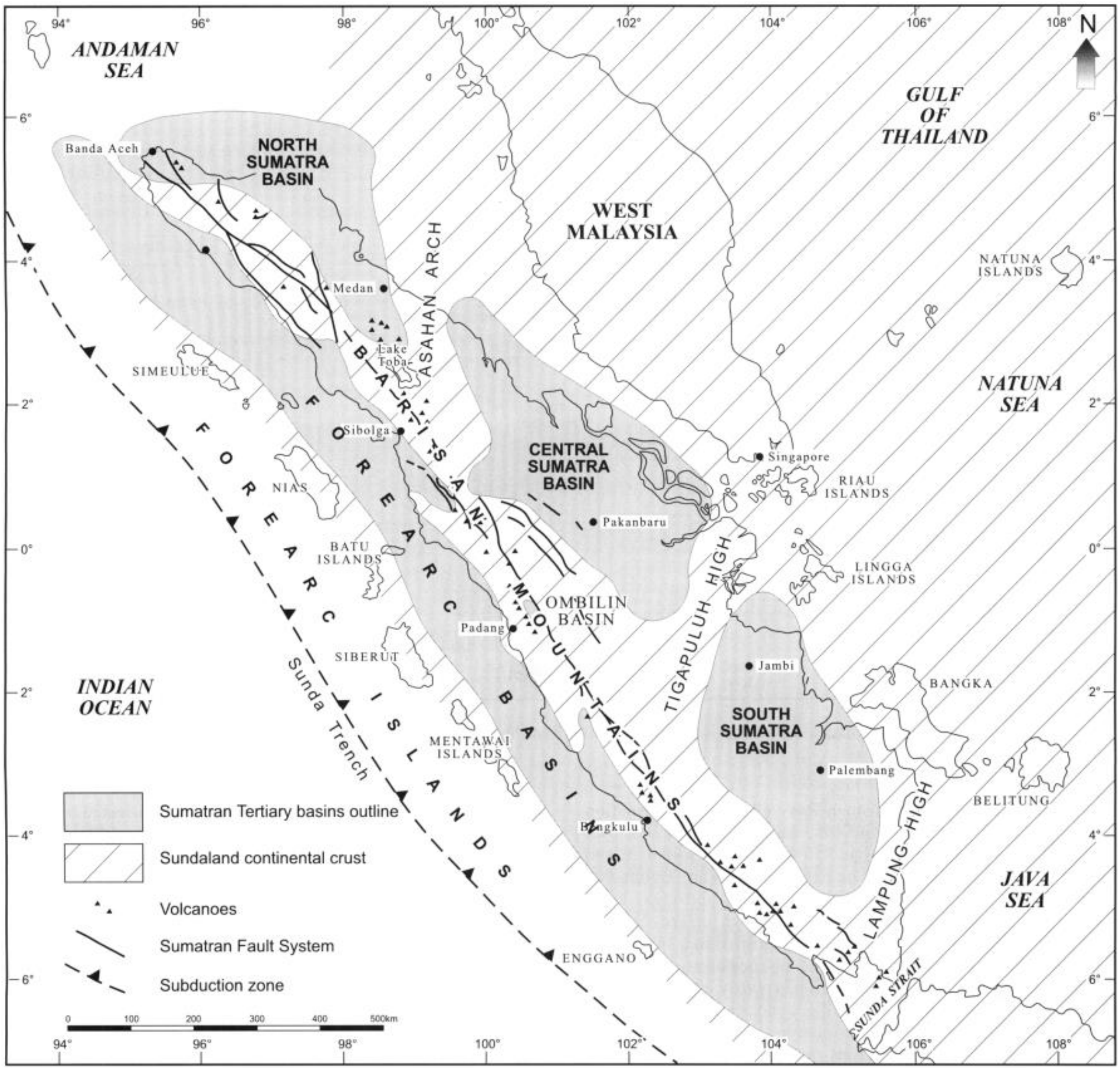

Figure 1. The geological setting of Sumatra [7]

c. Provenance

Provenance is the study of the origin or source of sedimentary materials [3]. Provenance studies aim to identify the source region's originating rocks, paleoclimate, and tectonic setting. The origin rock type is interpreted based on the percentage of monocrystalline and polycrystalline quartz grains [10]. In the meantime, the degree of roundness and feldspar alteration level are used to interpret the paleoclimate of the source region [9], while the percentage of quartz (Q), feldspar (F), and lithic (L) [4] to determine the tectonic setting. The tectonic setting is classified into the continental block, magmatic arc, and recycled orogen, as depicted on Figure 2.

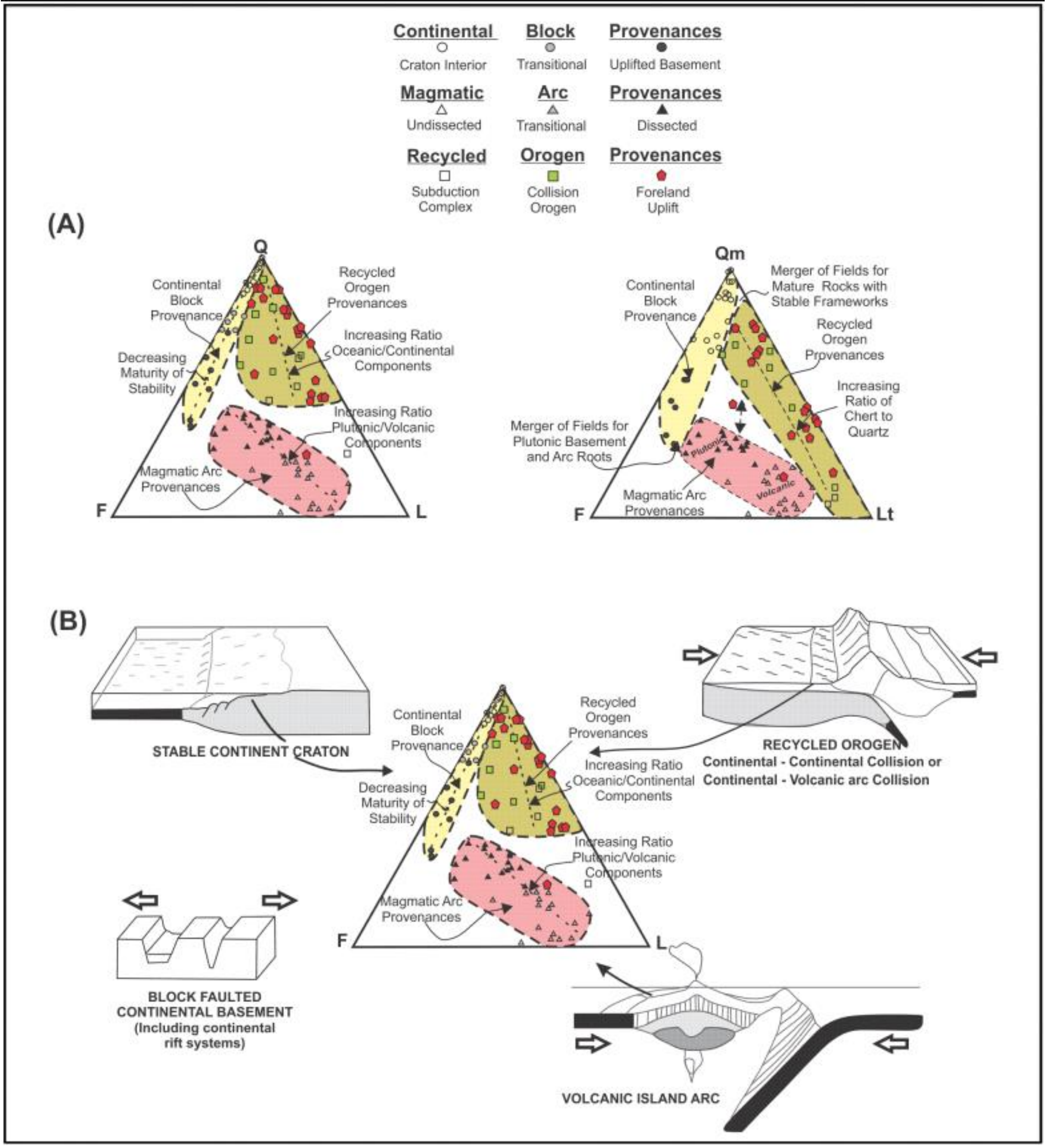

Figure 2. (a) Q-F-L and Qm-F-Lt diagrams and (b) illustration of the tectonic setting [3]

The provenance characteristics are mentioned in Table 1 [11, 12]. In Table 1, the four main provenances have distinct characteristics of the sand composition. Continental blocks are formed by stable cratons and basement uplifts, which are tectonically consolidated regions of integrated old orogenic belts that have been eroded to deep levels. Quartzose sands are typically yielded from the granite-gneiss basement and the recycled older sedimentary strata that are deposited on the stable craton or transported to the continent's passive boundaries. On the other hand, basement uplifts, which are areas of high relief along rifts and strike-slip zones, are deposited quartz–feldspathic sands, but lithic-poor, in extensional and pull-apart basins. The magmatic arc, which is associated with both continental and island arc subduction-related, produce sands with high contents of volcanic rock fragment. If the source rocks are plutonic rocks, the quartzofeldspathic fragment is produced. Further, recycled orogens form mountain belts. It will produce quartz–lithic sediment, but the composition of feldspar and lithic is low [11,12].

Table 1. The main provenance of terranes, their tectonic setting, and the typical composition of sand

Provenance	Tectonic setting	Constituents of The Sand
Stable craton	Continental interior, passive margin	Quartz grains, Qm/Qp and Fk/Fp are all high
Basement uplift	Transform rupture, rift shoulder	Low lithic fragment quartz-feldspar sands, similar Qm/F and Fk/Fp to bedrock ratios
Magmatic arc	Island arc, active continental margin	Feldspath-lithic (F-L) volcaniclastic sands with high P/K and Lv/Ls ratios that grade into quartzo-feldspathic (Qm-F) batholithic sands
Recycled orogen	Subduction zone, fold-thrust belt	Quartz-lithic (Qt-Lt) sediments have variable Qm/Qp and Qp/Ls ratios and low F and Lv content.

Experimental Method

According to the field data, the lithology conditions of the Rampong Formation in the research area consist of 26 sandstone observation points (Figure 3). Then, we performed a petrographic analysis on five thin-section samples of sandstone. Five samples were selected based on grain size differences observed in hand specimen samples.

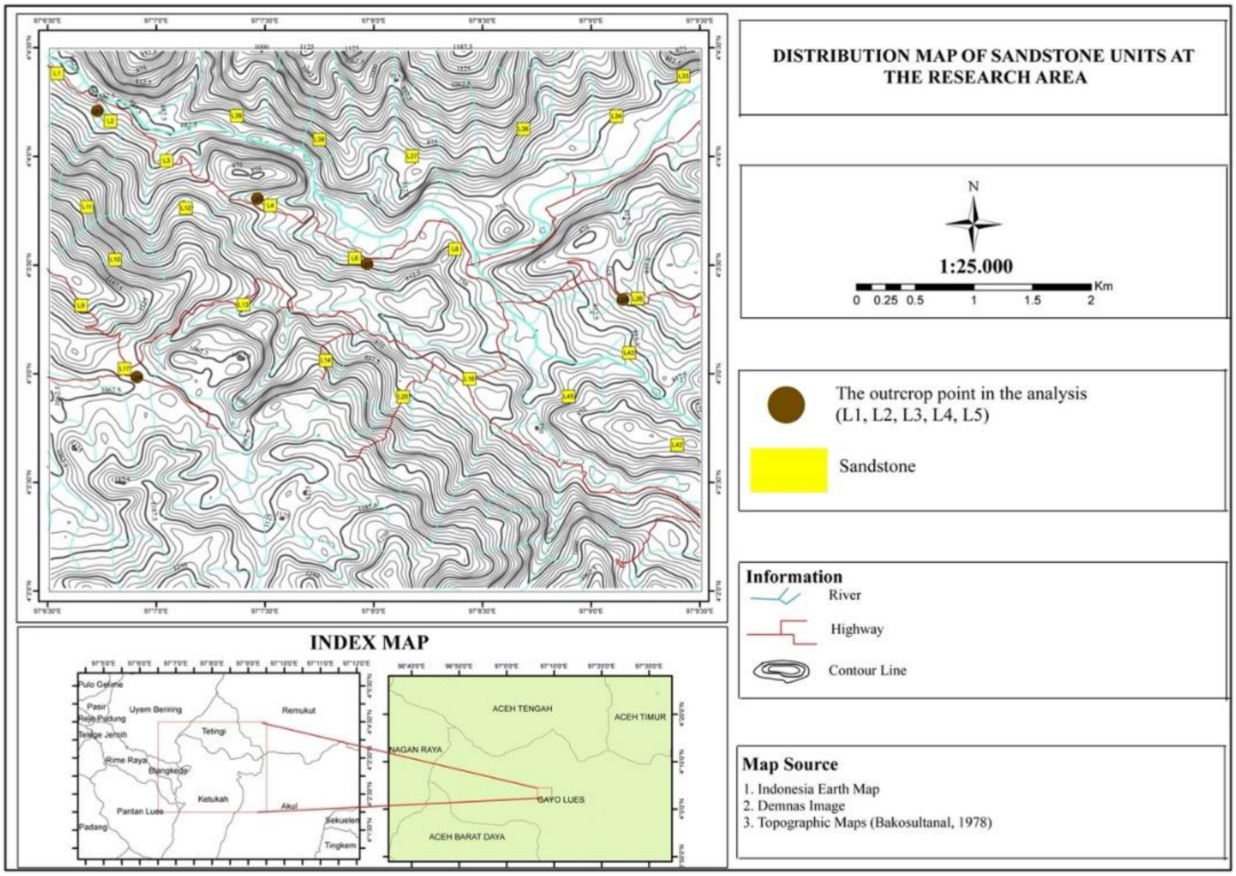

Figure 3. Distribution Map of Sandstone Unit at the Research Area

Petrography is a detailed description of rocks using 0.03-millimeter-thick samples [13]. We analyze the thin sections using a polarizing microscope to determine their mineral composition. In addition, we characterize the grain size, roundness, sorting, fabric, and porosity of the sandstone [3,12,14]. The method for calculating mineral percentages in grains is point counting [10] with the JmicroVision software. The constituent minerals of sandstones are classified according to their composition: monocrystalline and polycrystalline quartz, k-feldspar, plagioclase, rock fragments, and matrix. The percentages of quartz (Q), feldspar (F), and lithic (L) composition are plotted in the Q-F-L diagram to classify sandstones [16], to analyze tectonic setting [17], paleoclimates [18], and origin rock type [6,19].

Result and Discussion

The Rampong sandstone outcrops have a massive structure with a yellowish-white color, a grain size of about 1/8 millimeters, a well-sorted, and are not reactive to HCl. Based on petrographic analysis of five thin sections of sandstones, the texture consists of grains ranging in size from 0.1 mm to 0.5 mm, is well sorted, is sub-rounded to rounded of roundness, has closed packing, long contacts fabrics, and is not porous (Figure 4).

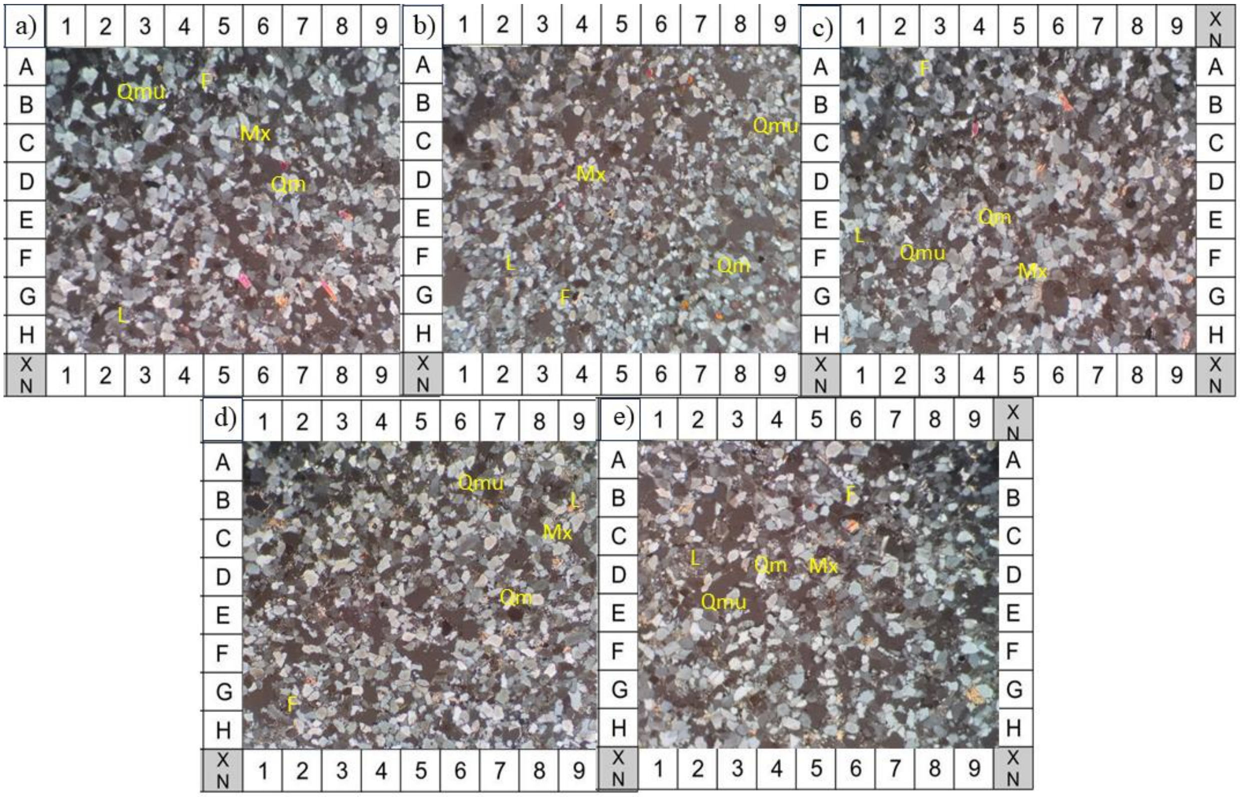

Figure 4. Rampong sandstone thin section a) A1, b) A2, c) A3, d) A4, and e) A5 sample code (Qm=Non-undulating monocrystalline quartz, Qmu=Undulating monocrystalline quartz, F=Feldspar, L=Lithic fragment, Mx=Matrix)

Table 2 displays the mineral composition of the Rampong sandstones. Monocrystalline quartz is both undulatory and non-undulatory. The undulatory monocrystalline quartz exhibits undulose extinction when rotated. It occurs in metamorphic sources that are under pressure. It also presents orthoclase, a type of K-Feldspar; the lithic is predominantly sandstone.

Table 2. Mineral composition of sandstone from the Rampong Formation (Qz=quartz, Qm=Non-undulating monocrystalline quartz, Qmu=Undulating monocrystalline quartz, Fsp=Feldspar, LF=Lithic fragment, Op=Opaque, Mx=Matrix)

Sample code	**Composition (%)**							**Total (%)**
	Qz			Fsp	LF	Op	Mx	
	Qm	Qmu	Total Qz					
A1	35	25	60	17	7	10	6	100
A2	55	9	64	15	10	0	11	100
A3	50	15	65	10	17	0	8	100
A4	45	13	58	12	20	0	10	100
A5	44	12	56	16	15	0	13	100

The sandstone classifications use the normalized Q-F-L diagram [11] in Table 3. The matrix percentage in the sandstone samples is <15%; therefore, the sandstone type is arenite (Figure 5).

Table 3. Normalized Q-F-L composition of Rampong Formation sandstone (Q=Quartz, F=Feldspar, L=Lithic fragment).

Sample Code	Normalized composition (%)				Rockname (Pettijohn, 1975)
	Q	F	L	Total	
A1	71.4	20.2	8.3	100	Sub-arkose
A2	71.9	16.9	11.2	100	Sub-arkose
A3	70.7	10.9	18.5	100	Sub-litharenite
A4	64.4	13.3	22.2	100	Sub-litharenite
A5	64.4	18.4	17.2	100	Sub-litharenite

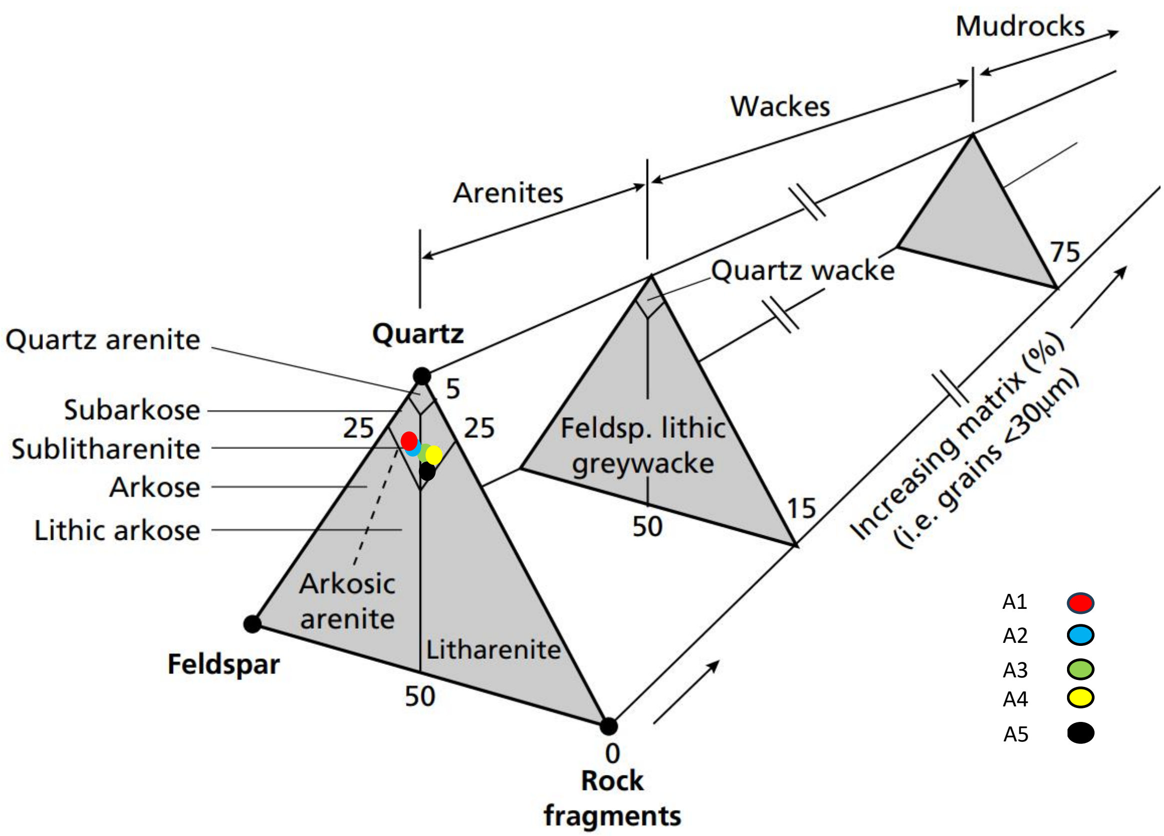

Figure 5. Classification of the Rampong sandstones [16]

Based on the matrix composition, the Rampong sandstone's maturity is low to medium [8]. Additionally, the long contact indicates that these sandstones had undergone moderate burial. Consequently, the grains are so close together that there is no pore. These sandstones were transported over long distances; their grain shape ranges from subrounded to rounded.

Tectonic Setting

Tectonic settings are determined by quartz, feldspar, and lithic fragment (Q-F-L) composition [4]. The results are depicted in Figure 6. The tectonic setting of the five Rampong Formation sandstone samples is recycled orogen. The provenance of a recycled orogen is a subduction complex or fold-thrust belt.

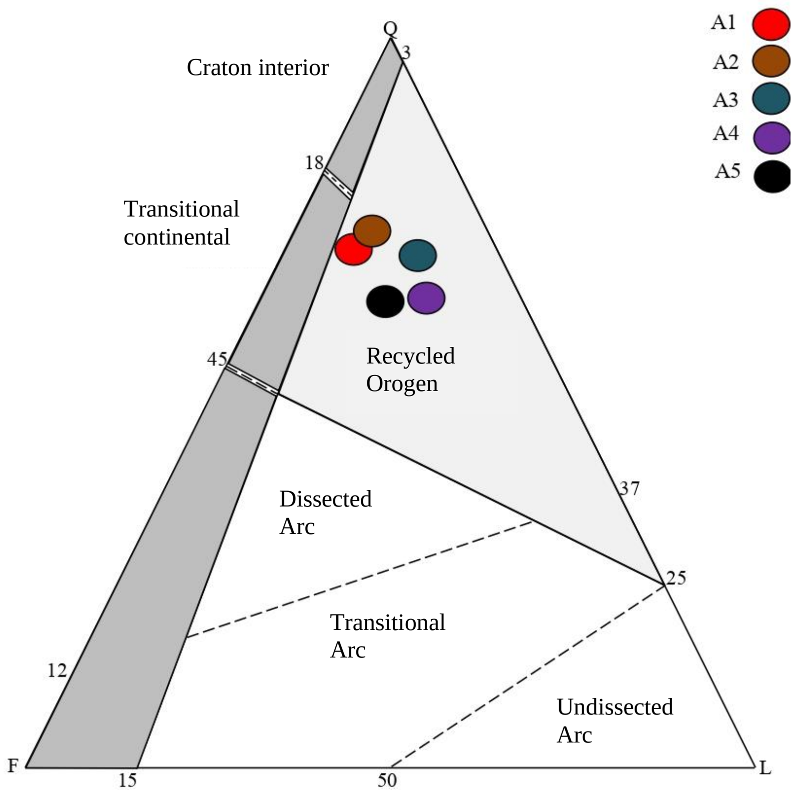

Figure 6. The Rampong sandstone provenance [17]

Figure 7 shows the tectonic process of uplift generates various types of sedimentary rock to occupy the foreland basins. The Tertiary subduction, where the Indo–Australian plate was subducted to the Eurasian plate, is responsible for forming the Rampong sandstone. Older rocks were exposed to the surface due to the tectonic processes and were weathered. Minerals resistant to weathering like quartz and feldspar tend to undergo transportation and diagenetic processes to form Rampong sandstones.

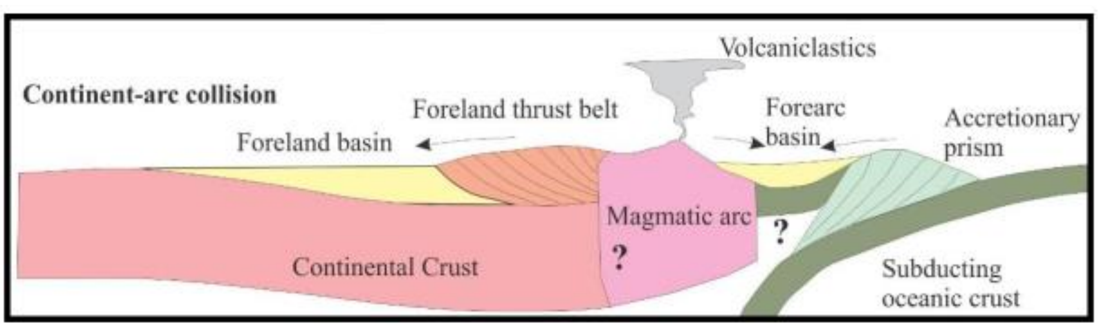

Figure 7. The tectonic setting generating recycled orogenic sand [4]

The Rampong sandstones mostly consist of quartz and its lithic and low feldspar. It is typical of the recycled orogen provenance. Quartz makes of 64.4% to 71.9% of the samples, feldspar 10.9% to 20.2%, and lithic 8.3% to 22.2%. The abundant presence of quartz minerals compared to feldspar and lithic is because quartz is resistant to weathering.

Source rock type

Sandstones are derived from older rocks that have undergone weathering, transportation, and diagenetic processes, including igneous rocks, metamorphic rocks, and even sedimentary rocks. Since these rocks compositions differ, the remaining weathering minerals will be varied. Unfortunately, some minerals, like quartz and feldspar, can be found in igneous, volcanic, metamorphic, or sedimentary rocks. Therefore, the provenance analysis considers the characteristics of the minerals.

The origin rock is identified based on undulating as well as non-undulating monocrystalline quartz and 2-3 or >3 polycrystalline quartz (Figure 8). Undulating monocrystalline quartz is often derived from metamorphic rocks. In contrast, non-undulating monocrystalline quartz is typically originated from igneous rock.

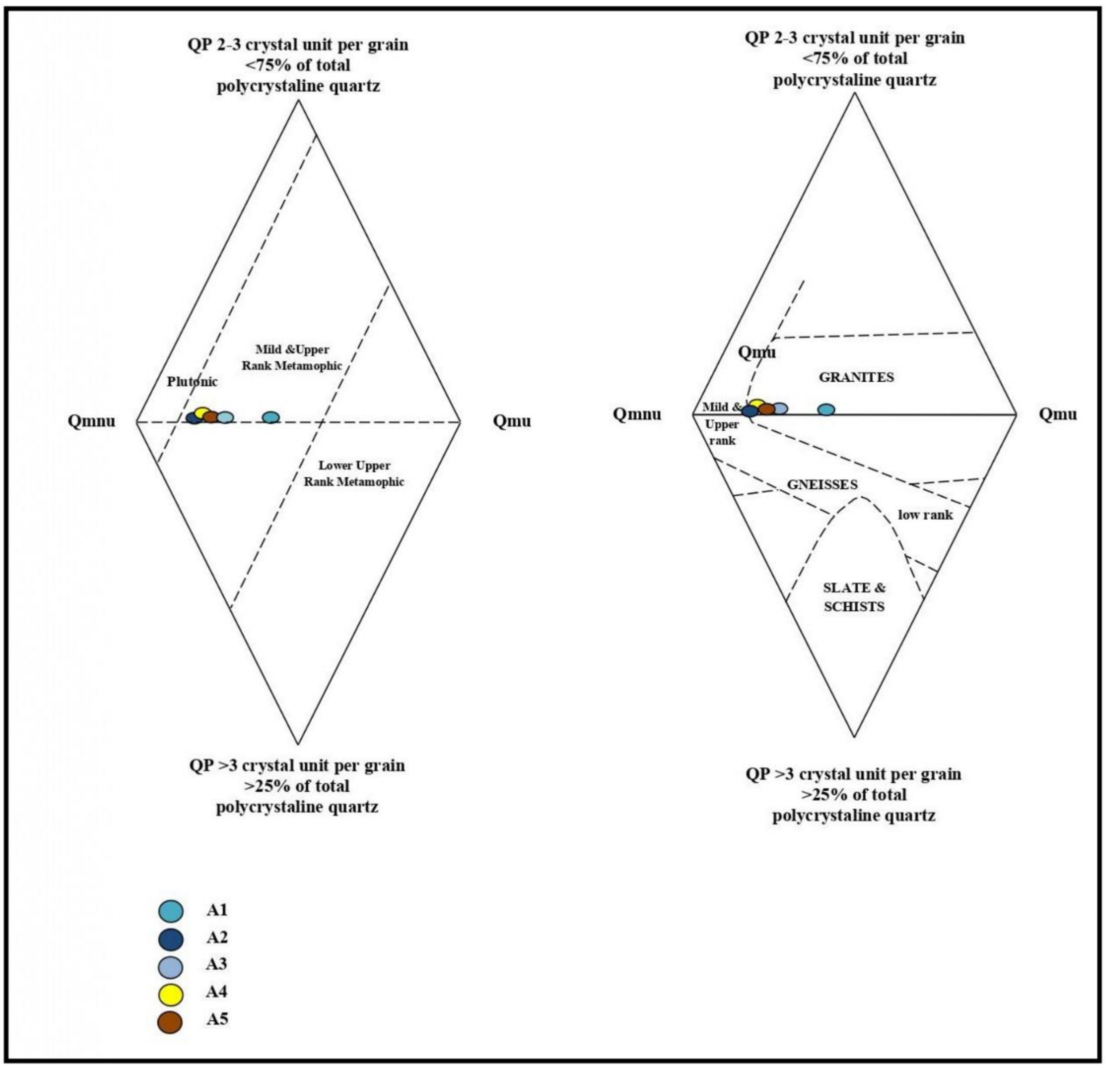

Figure 8. The source rock type of the Rampong sandstone [18]

The plotting diagram exhibit that the Rampong sandstones were sourced from granite and experienced a low metamorphic process. The presence of non-undulating monocrystalline quartz grains indicates its origin in igneous rock, granite [20]. Some undulating monocrystalline quartz was caused by pressure when the Eurasian and Indo-Australian subduction occurred during the Tertiary period. These granite rocks are interpreted to originate from intrusive rocks that formed in the Late Cretaceous to the Eocene [1]

Feldspar minerals such as orthoclase and microline are typically found in felsic plutonic rocks like granite and highly metamorphosed rocks like gneiss [14][21]. However, the Rampong sandstones are produced from granitic plutonic rock since the samples are predominantly non-undulating monocrystalline quartz and are present orthoclase minerals. Granite is a felsic igneous rock with a primary composition of quartz and k-feldspar; these minerals are difficult to weather, so they are lithified into sedimentary rocks through a diagenetic process.

Paleoclimate of Source Area

Determination of paleoclimate also takes the composition of quartz, feldspar, and lithic fragments but applies another diagram [18]. The plotting diagram reveals that the paleoclimate of the Rampong sandstones was sourced as humid (Figure 9).

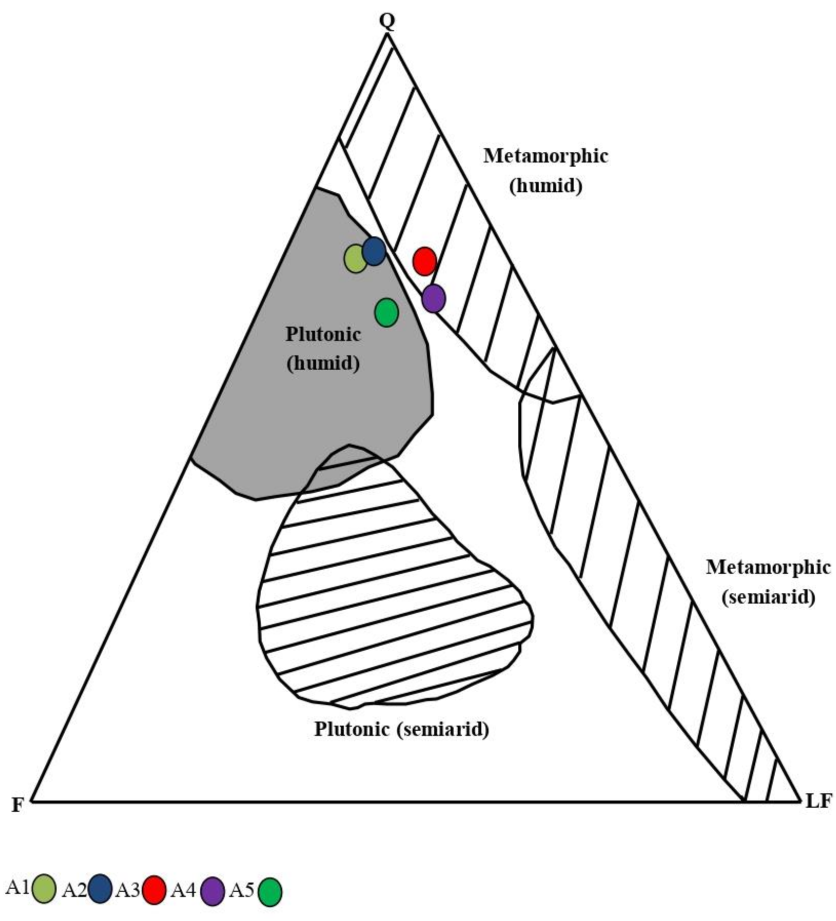

Figure 9. Paleoclimate diagram of the Rampong sandstone [19]

The humid environment contributes to chemical weathering in order for the outcrops of rock to be weathered rapidly. Resistant minerals, like quartz, are abundant in Rampong sandstone. While orthoclase is also found but in small numbers and is cloudy in thin-section photographs due to alteration. It proves that the humid climate had an effect on the source rock so that the remaining abundant minerals are quartz which are truly resistant [21]. These minerals will survive so that lithified to form sedimentary rock. It is distinct from mafic intrusive igneous rocks, made up of minerals like olivine, pyroxene, and others. These minerals are more susceptive to weathering. These minerals are not resistant in a humid environment; thus, they do not go further into processes that form sedimentary rocks.

Conclusion

The Rampong sandstone originated from the late Cretaceous to Eocene intrusive granitic rock. The granite experienced low metamorphism during the Eurasian and Indo–Australian subduction. The Rampong sandstone type is interpreted to originate from a recycled orogen and the paleoclimate of the source rock was humid.

Acknowledgment

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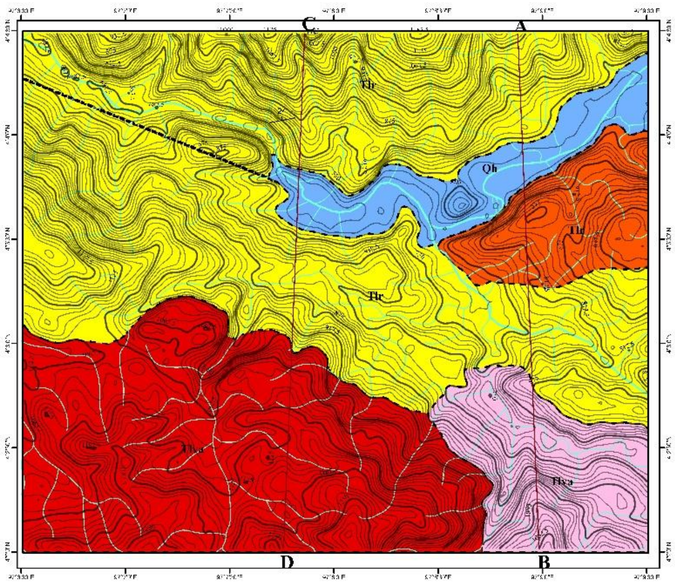
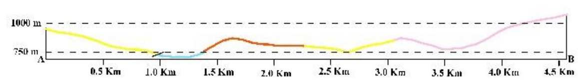
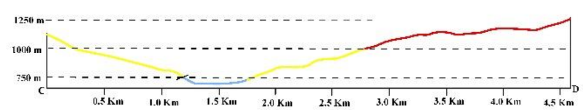
Appendix 1. Geological Map of The Research Area

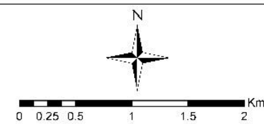


GEOLOGICAL VIEW PROFILE
SCALE 1:1
VERTICAL : HORIZONTAL





GEOLOGICAL MAP OF THE RESEARCH AREA

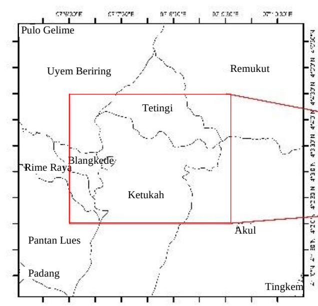


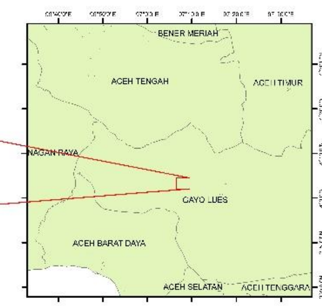
Legend

River Contour line A —— B Cross sectional ------- Fault uncertain Strike/dip

Age		Formation		Lithological unit	Unit Color	Information
Era	Period	Sediment	Volcanic			
Quarter	Holocene	Qh		Alluvial		Alluvial deposit unit cover 5% of the entire study area, composed of loose materials such as gravel, sand and clay
Tersier	Late Oligocene – Early Miocene		Tlva	Agglomerate		Agglomerate unit cover 15% of the entire study are. A gray to brownish in color, grain size (fragment >64 mm), andesite is present as fragment, highly weathered
			Tlva	Andesite		Andesite unit cover 20% of the entire research area. Grayish black in cover, degree of crystallization, holocrystalline, inequigranular fabric, subhedral crystal form, large to fine faneritic grains, moderate weathering
		Tlr		Conglomerate		Conglomerate unit cover 10% of the entire study area. White – yellowish in color, cobble fragment size, weak – medium weathered, weak compaction
		Tlr		Sandstone		Sandstone unit cover 50% of the entire study area, white in color, very fine sand grain size to medium sand, good porosity, medium compaction, do not react to HCl.

INDEX MAP





Map Source
1. Indonesia Earth Map
2. Demnas Image
3. Topographic Maps