Geological, Geomechanical and Geochemical Analysis on Claystone Of The Warukin Formation

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Research Article

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Abstract

This study was conducted to determine the characteristics of Warukin claystone by carrying out 3G approach (geology – geomechanics and geochemistry). The aim of this is to provide the latest information on characteristics of Warukin claystone which may later be used for various purposes. Results of the study showed that the provenance of Warukin claystone was from recycled orogen. This was corroborated by the geochemical data which stated that the claystone was composed by clay-sized quartz minerals. Clay-sized quartz minerals indicate that there has been a long process of transport and weathering of the quartz minerals that have high resistance according to the Goldich series, until they become clay-sized. This finding has changed the paradigm so far that says that the Warukin claystone is composed of clay minerals, which is actually composed of clay-sized quartz minerals. The other geochemical data result is the absence of minerals from volcanic rocks that appear at the beginning of the Bowen series, which have fragile property. As a result of the recycled process, the fragile minerals were not found in claystone of the Warukin Formation. Mg is the fragile element that was not found and the mineral is an element binding in montmorillonite, so the presence of the montmorillonite in claystone of the Warukin Formation was also not found. Geomechanical data result shows that Warukin claystone had strength of around 100 kPa with internal friction angle of about 14° and cohesion of about 29 kPa. The results of 3G analysis had provided new answers that claystone of the Warukin Formations is composed by clay-sized quartz and the existence of montmorillonite is unlikely to be found in the Warukin Formation. Both of these corroborate the analysis that claystone of the Warukin Formation is from recycled orogen.

1. Introduction

The Warukin Formation is the main formation in the Asam-Asam sub-basin where there is abundant coal resource, so it is interesting to study the rocks forming this formation. Not only coal deposit, but also clay and quartz, which are popular industrial raw materials, can be found in the formation. Claystone is very widespread and becomes one of the dominant lithology in the Warukin Formation. Claystone has many uses for various purposes, so knowing the details of claystone is very important as data requirement for industrial raw materials. Knowing claystone characteristics from the provenance, the physical and mechanical properties, and also the geochemical properties are very necessary. Information of geology – geomechanics and geochemistry (3G) will be the basic data for engineering needs. Geological information is related to the constituent mineral which is very useful in determining the provenance as well as the characteristics of claystone, so it can explain the prediction of certain unfavorable minerals presence in the Warukin Formation. Geomechanical property is related to rock strength and it provides a visualization of vertical and horizontal distribution of the rock strength, thus it can be used as a reference for demolition activity. Geochemical property will be very helpful in detailing claystone of the Warukin Formation and its relationship to the other minerals that need to be aware of. One of the clay minerals to be aware of is montmorillonite which is a clay mineral that has high swelling property. This 3G study (geology – geomechanics and geochemistry) is expected to provide detail explanation of potential presence of montmorillonite mineral in the Warukin Formation.

In geological study, especially in relation to provenance analysis, studying regional geological setting is very important. Different tectonic settings have different characteristics of rock [1]. For clastic sedimentary rock, the characteristic can be classified based on grain composition of the rock constituents. The grain size follows Wentworth rule (1992) [2]., while for fine-grained clastic sedimentary rock, it follows Tucker classification (1996). (Fig. 1). This grain size is the basis for naming fine-grained sedimentary rock. When 75% – 100% of the rock is composed by a certain grain size, the rock will be named the same as the name of the grain size. The other grain size with composition of no more than 25% will be attached behind the name of the rock. For example, "sandy claystone" is composed by 75% clay-sized grain and 25% sand-sized grain. The naming of mudstone is based on balanced grain composition between clay, sand, and silt [3]. According to the classification of [4]., clastic sedimentary rock is classified petrographically based on the percentage of quartz (Q), feldspar (F), and rock/lithic fragment (L) in the form of a triangle combined with the percentage of the matrix content (Fig. 2).

Pre-deposition history of sediment or sedimentary rock may be reconstructed through provenance analysis [5]. The provenance analysis studies the distance, direction, tectonic setting, climate, and relief of the origin area of sedimentary material [6]. The main assumption underlying provenance analysis is that different tectonic settings consist of different rock types with characteristic of producing a specific composition range of sandstone when eroded. The composition of sandstone reflects not only rock of the source area but also tectonic setting of the sandstone source area [7], [8]. used the QFL and QmFLt diagrams (Fig. 3) linking the composition of sandstone detritus with the main type of provenance consisting of continental block provenance (including sub-provenance craton interior, transitional, and uplifted basement), magmatic arc provenance (including sub-provenance undissected arc, transitional arc, and dissected arc), and recycled orogen provenance (including sub-provenance subdiction complex, collision orogen, and foreland uplift).

In the QFL diagram (Fig. 3, on the left), Qt = Qm + Qp, which is total detritus number of monocrystalline quartz (Qm) and polycrystalline quartz (Qp); F is number of feldspar detritus; and L = Lv + Ls + Lm, which is total detritus number of volcanic rock fragment (Lv), sedimentary rock fragment (Ls), and metamorphic rock fragment (Lm). In the QmFLt diagram (Fig. 3, on the right), Qm is number of monocrystalline quartz detritus and Lt = L + Qp, which is total detritus number of rock fragments added with number of polycrystalline quartz detritus. These two diagrams are used as a reference to determine provenance.

In general, the Warukin Formation is composed by sandstones, claystones, and coal. Sandstone dominates the rock outcrops, while claystone is only an insert. Study on sandstone of the Warukin Formation has been carried out by [9]. The result was the provenance of Warukin standstones is generally recycled orogen with subclassification of quartzose recycled.

1) Regional geology

Tectonic activity in Kalimantan has occurred since the Jurassic period. Ultramafic rocks and metamorphic rocks at that time were mixed and then intruded by granite and diorite in the Early Cretaceous or earlier. At the end of the Early Cretaceous, the Alino Group that was partly an olistostrome was formed, interspersed by volcanic activity of the Pitanak Group. The tectonic activity continued, until in the Early Cretaceous, it caused the ultramafic rocks and metamorphic rocks faulted over the Alino Group. In the Paleocene epoch, the tectonic activity caused uplift of Mesozoic rocks, accompanied by intrusion of porphyry andesite rock.

In the Late Cretaceous epoch, Kalimantan microcontinent and the Paternoster plate were collided, causing the southeastern part of Kalimantan to be uplifted. The area, later in the Early Tertiary, became an environment for the development of lacustrine deposit and alluvial fan of the Lower Tanjung Formation. A marine transgression in the beginning of the Middle Eocene resulted in domination of fluvio-deltaic sediments and eventually formed the Central Tanjung Formation, which was dominated by sea sediments. Then, the marine transgression gradually submerged the uplifted area, forming the upper part of the Tanjung Formation and the Berai Formation thereafter in the Late Eocene until the Early Oligocene. In the Miocene epoch, the deposits of the Warukin Formation were formed as a result of sea level decline due to the uplift of the Schwaner Mountains in the west and the Meratus Mountains in the middle. The uplift of the Meratus Mountains continued until the Pleistocene epoch, resulting in rock deposits of the Dahor Formation.

Rock formations in the study area are dominated by the Warukin Formation and, in some other parts, composed by the Berai Formation and the Tanjung Formation. These formations are in the Asam-Asam Basin, which is a part of the Barito Basin in South Kalimantan. The Barito Basin is divided into the Barito Basin and the Asam-Asam as a sub-basin (Fig. 4). These two basins are believed to be a depocentre in the Eocene epoch that were connected and separated due to uplift of the Meratus Mountains in the Late Miocene [10]. The general stratigraphy consists of Mesozoic bedrock and Cenozoic sedimentary rocks (Fig. 5). Cenozoic sedimentary deposits covering Mesozoic bedrock include the Tanjung Formation, the Berai Formation, the Warukin Formation, and the Dahor Formation [11].

The Tanjung Formation was formed during the Eocene epoch. This formation is dominated by fluvio-tidal sediments carrying coal seams to a marginal marine environment. The lithology is generally sandstone, carbonaceous claystone, and coal.

The Berai Formation was conformably deposited above the Tanjung Formation at the southern part of the basin. This formation was entirely influenced by marine environment. The Berai Formation is characterized as shallow-marine carbonate shelf rocks with lithology generally of claystone, marlstone, and limestone. The age of this formation is Early Oligocene to Middle Oligocene.

The Warukin Formation was conformably deposited above the Berai Formation. This formation showed deposition of a shallow marine that later became a fluvio-deltaic environment. The lithology is generally claystone, sandstone, and coal. Coal resources and reserves spread from the southwest to the northeast. The Warukin Formation is considered as a coal bearing formation [12]. The age of this formation is

Middle Miocene - Late Miocene. The Warukin Formation is a major part of the rock unit revealed in the study area.

2) Geomechanics

Degradation of physical and mechanical properties of rocks is very likely to occur in rocks after exposure, especially in fine-grained sedimentary rocks such as claystone and sandstone. Weathering process occurs when rocks are exposed and gives impact on changes in the physical and mechanical properties of rocks. Degradation of mechanical properties in sedimentary rocks is influenced by 7 factors [14]. The factors are rock porosity, grain size distribution, quartz content, material density, average grain size, pore filler cement, and feldspar mineral content.

Stability of mineral forming the main rock (resistance to weathering) is expressed by Goldich series (Fig. 6). In this series, quartz is the most stable, followed by feldspar, mica, and other less stable minerals which are only present when weathering has occurred slightly. This Goldich series can explain mineral resistance to rock, so in analysis, it is combined with minerals obtained from mineralogical or petrographic tests, so that it will be able to strengthen the geological analysis (provenance).

Chemical process is characterized by entry of water and air into material to form a chemical reaction that can change the mechanical properties of rock [16]. Rock exposure that affects degradation of crystalline rock [17]. Weathering and degradation processes in mudstone and siltstone has a shorter time compared to weathering in crystalline rock [18]. Testing of mechanical properties on sedimentary rock in wet and dry conditions produces a significant difference between the two conditions [19]. Composition of clay mineral in rock influences the mechanical properties and the slope stability [20]. Composition and properties of clay mineral affects mechanical properties of rock [21]. The clay minerals are illite, montmorillonite, and kaolinite. Mineralogy of weak rocks is tended to be composed by clay mineral with limited silica mineral [22]. Clay mineral can increase the value of cohesion but reduce the value of internal friction angle. To improve the mechanical properties of clay mineral, a combination of maintaining physical properties and compaction to the material must be carried out [23].

3) Geochemistry

Petrographic analysis examines mineral composition and grain size. The results of petrographic analysis on sedimentary rocks will provide information about the composition of quartz, feldspar, and lithic. Based on this information, the rock samples can be classified. Understanding in the mineral composition can help in analyzing the provenance of sedimentary rock. It is done by identifying composition of the clastic sediment and its relationship to the genesis as well as the tectonic position. Provenance environment can be determined through composition analysis due to the fact that composition of fragments and minerals in a rock are influenced by the genesis of sedimentary rock formation at a certain tectonic position.

Clay minerals can be classified based on the mineral structure into 4 groups [24]., which are: Kaolin group (1:1), Hydrous mica group (2:1), Montmorillonite group (2:1), and Chlorite group (2:2)

One of weathering processes that commonly occurs in clastic sedimentary rocks is hydrolysis. Hydrolysis occurs due to replacement of cations in crystal structure by hydrogen, thus the crystal structure is damaged and destroyed. Hydrolysis is the most important chemical weathering because it can produce perfect destruction or drastic modification to easily-weathered minerals. The other common weathering process is feldspar weathering into clay minerals that can be kaolinite and illite. The Warukin Formations is composed by illite and kaolinite [25].

2. Materials And Methods

The study was conducted on claystone of the Warukin Formation in the Asam-Asam Basin, on the physical character and the mineral composition. Claystone samples were obtained from several cross sections in Kusan Block, Tanah Bumbu, South Kalimantan, by two ways that are sampling based on core drilling results in HQ size and sampling using undisturbed sample tubes on slope surfaces after mining activity. The samples were determined by purposive sampling method. The samples obtained were then analyzed at the Geotechnical Laboratory and the Mineralogy Laboratory. Handling of the samples from field to laboratory was managed according to standard of sample management to maintain the rock properties.

Geomechanic testing was carried out to obtain the physical and mechanical properties of claystone. For all samples, unconsolidated undrained triaxial test was performed to obtain values of cohesion and internal friction angle, as well as uniaxial unconfined compression strength test to obtain values of strength and strain. Physical property tests were carried out on all mechanical property tests.

Mineralogy of claystone was studied through petrographic analysis. Petrographic analysis is required to understand the mineral composition and grain size of claystone. The analysis was carried out on samples that had physical similarities based on sedimentary rock description. Scanning Microscope Electron (SEM) was operated to obtain an overview of the mineral structure patterns of claystone. With this information, the type of claystone was specifically determined.

Mineralogical testing was carried out by X-Ray Diffraction (XRD) to characterize the mineral composition of claystone. The mineralogical testing was followed by a Loss on Ignition (LOI) test using the X-Ray Fluorescence (XRF). LOI values need to be known to determine the weathering speed of rock mass.

Variables of claystone examined in this study include the physical properties that are water content, void ratio, and wet density; as well as the mechanical properties that are cohesion, internal friction angle, and compressive strength. Variables relating to claystone mineral include Loss on Ignition (LOI) examined using XRF and mineral composition identified using X-Ray Diffraction (XRD). Mineral composition and grain size were obtained from petrographic analysis.

3. Results

3.1. Petrographic analysis

Samples were taken from the surface along outcrop at the study area by using a geological hammer. However, only 8 samples obtained that represented the overall study area. Besides, the samples were also selected by considering the condition that allowed them to be used as thin sections for petrographic analysis.

Claystone samples that has been made into thin sections were analyzed petrographically by a polarizing microscope with the aim of determining the abundance of claystone constituent materials (Fig. 7). The results, which are data of the constituent materials abundance as well as the percentage of quartz, feldspar, and lithic as the constituent materials, are shown in Table 1 and Table 2.

Table 1. Composition of Warukin claystone by petrography analysis.

Sample	Abundance (%)			
	Quartz	Feldspar	Organic carbon	Matrix (clay mineral)
C1	14	-	4	75
C2	15	2	3	80
C3	10	-	3	87
C4	10	-	3	87
C5	10	1	4	84
C6	2	-	1	98
C7	20	2	23	55
C8	5	1	2	92

Table 2. Percentage of quartz (Q), feldspar (F), and lithic (L)

Sample	Abundance (%)		
	Quartz	Feldspar	Lithic
C1	77.78	0.00	22.22
C2	75.00	10.00	15.00
C3	76.92	0.00	23.08
C4	76.92	0.00	23.08
C5	66.67	6.67	26.67
C6	66.67	0.00	33.33
C7	44.44	4.44	51.11
C8	62.50	12.50	25.00

The abundances observed in claystone samples were quartz minerals (monocrystalline) in range of 2–15% with average of 9.4%, feldspar in range of 1–2% with average of 1.3%, carbon material (disintegration product of coal) with range of 1–4% and average of 2.9%, and matrix of clay mineral in range of 75–98% with an average of 86.1% (Table 1). Sample with code number C7 showed different data behavior from the other samples. The abundances of C7 were 20% quartz, 2% feldspar, 23% carbon material, and 55% matrix of clay mineral.

Claystone was classified based on the composition of quartz, feldspar, and lithic in Table 2. Referring to the classification of clastic sandstones [4]., claystone sample data was plotted against the classification diagram. The results are C1, C2, C3, C4, C5, C6, and C8 were classified as mudrock with matrix of more than 75%, while C7 was classified in the greywacke-lithic wacke group with matrix of 55% (Fig. 8).

3.2. Provenance analysis

Provenance of Warukin claystone was determined by using the results of petrographic observation. Classification by Dickinson and Suczek in 1979 (Dickinson et al., 1983) [26]. was used to determine the provenance. The result was the provenance of Warukin claystone is generally recycled orogen with subclassification of quartzose recycled (Fig. 9).

3.3. Geochemical analysis

The results of geochemical test are shown in Table 3 for mineral composition analyzed by X-Ray Diffraction (XRD) and Table 4 for Loss on Ignition (LOI) analyzed by X-Ray Fluorescence.

As shown in Table 3, minerals in the chemical compound observed in the XRD test were quartz (SiO_2), kaolinite ($Al_3Si_2O_5(OH)_4$), and illite ($(KH_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)]$). Based on the XRD test, claystone of the Warukin Formation was composed by quartz of 57–69%, kaolinite of 24–28%, and illite of 9–17%.

Table 3. Identified minerals of Warukin claystone by X-Ray Diffraction (XRD).

Sample	Quartz (%)	Kaolinite (%)	Illite (%)	Total (%)
GRM_1	62	24	14	100
GRM_2	62	26	12	100
GRM_3	62	28	10	100
GRM_4	62	26	12	100
GRM_5	60	28	12	100
GRM_6	64	24	11	99
GRM_7	62	26	12	100
GRM_8	63	25	12	100
GRM_9	60	27	13	100
GRM_10	63	25	12	100
GRM_11	61	26	13	100
GRM_12	57	26	17	100
GRM_13	61	27	12	100
GRM_14	63	26	11	100
GRM_15	64	24	12	100
GRM_16	63	26	11	100
GRM_17	64	25	11	100
GRM_18	64	25	11	100
KS_1	62	28	10	100
KS_2	61	26	13	100
KS_3	59	27	14	100
KS_4	65	26	9	100
KS_5	69	26	13	108
KS_6	66	24	10	100
KS_7	60	25	15	100
KS_8	59	26	15	100
KS_9	60	26	14	100
KS_10	66	24	10	100

Sample	Quartz (%)	Kaolinite (%)	Illite (%)	Total (%)
KS_11	60	26	14	100
KS_12	60	28	12	100
KS_13	60	26	14	100
KS_14	60	26	14	100
KS_15	60	25	15	100
KS_16	59	27	14	100
KS_17	61	26	13	100

Quartz mineral reached 60% which was visually very fine-sized, so in Wentworth grain size classification (Wentworth, 1922), it fell into the clay size category. Minerals in claystone of the Warukin Formation were dominated by quartz minerals of various sizes ranging from sand to clay. This can be seen from the claystone composition which was dominated by clay-sized quartz.

So far, claystone of the Warukin Formation is considered to be a claystone composed by clay minerals. However, in fact, claystone is composed by clay-sized quartz minerals. The definition of clay must indeed be seen from two sides, as clay-sized grain or as clay minerals. Seeing the result, the clay in the Warukin Formation is considered as grain size not as clay mineralogy.

The types of clay found in the study area were only kaolinite and illite with the amount of about 20% and 10%, respectively. Montmorillonite was not found in the Warukin Formation because montmorillonite is related to magnesium (Mg), which is related to basaltic volcanic rocks. Basaltic rock consists of magnesium (Mg), iron (Fe), and calcium (Ca); for example, olivine and pyroxene, which are the first minerals in Bowen series. It means that they are fragile.

Petrographic test result showed that the Mg element was not found because the source rock (provenance) of the Warukin Formation was from material detritus of the previous formation. When volcanic rocks come to the surface, there will be deposited weathering in the Cretaceous and Eocene formations. The contribution of volcanic rock to the lithic was not found, so it can be ascertained that the source of the rock was not volcanic. With source rock that was not volcanic, the potential types of clay were kaolinite and illite. The Mg element as an ionic bond in 2:1 structure was absent, so the montmorillonite was not present in the Warukin Formation.

Table 4 shows the result of Loss on Ignition (LOI) analyzed by X-Ray Fluorescence. The LOI values are around 10%, which is a large number in weathering of sedimentary rocks. Change in the LOI values is related to exposure time. The longer the exposure time, the higher the LOI value. Increase in the LOI value is also associated with changes in mechanical properties. As LOI value increases, mechanical properties of rock decrease. The mechanical properties are cohesion, internal friction angle, and strength.

Table 4 .Loss on Ignition (LOI) of Warukin claystone by X-Ray Fluorescence (XRF).

Sample	Unit	Parameter
		Loss on Ignition (LOI)
GRM_1	%	10.39
GRM_2	%	9.42
GRM_3	%	8.87
GRM_4	%	9.31
GRM_5	%	9.84
GRM_6	%	8.87
GRM_7	%	8.60
GRM_8	%	9.08
GRM_9	%	10.15
GRM_10	%	9.26
GRM_11	%	10.70
GRM_12	%	12.27
GRM_13	%	10.04
GRM_14	%	8.63
GRM_15	%	8.65
KS_1	%	8.57
KS_2	%	10.50
KS_3	%	11.21
KS_4	%	7.78
KS_5	%	10.00
KS_6	%	7.82
KS_7	%	10.71
KS_8	%	11.01
KS_9	%	10.69
KS_10	%	7.80
KS_11	%	10.73
KS_12	%	9.79

Sample	Unit	Parameter
		Loss on Ignition (LOI)
KS_13	%	10.40
KS_14	%	9.80
KS_15	%	11.22

Scanning Electron Microscopic (SEM) was performed on all claystone samples with magnification of 8000x. Samples were taken from in situ claystones that were not exposed to the surface. As seen in Fig. 10, the result shows that structure of the claystone sample formed multiple thin sheets that were well-ordered. This indicated that the claystone was not experienced disruption. If the claystone is weathered, pattern of the structure will be irregular or there wil be disruption on those sheets.

3.4. Geomechanical analysis

The results of geomechanical test for the physical properties, namely water content, void ratio, and wet density, as well as for the mechanical properties, namely cohesion, internal friction angle, and compressive strength, are shown in Table 5. Based on the results, claystone of the Warukin Formation had:

- Water content ranging from 13.80–30.42% with an average of 23.70%
- Void ratio ranging from 0.49–0.70% with an average of 0.62%
- Wet density ranging from 1.68 g/cm3 to 2.16 g/cm3 with an average of 1.89 g/cm3
- Cohesion ranging from 19.83 kPa to 51.43 kPa with an average of 29.50 kPa
- Internal friction angle ranging from 8.78° to 30.42° with an average of 17.15°
- Compressive strength ranging from 21.49 kPa to 396.99 kPa with an average of 99.93 kPa

Table 5. The physical and mechanical properties of Warukin claystone.

Sample	Water content (%)	Void ratio (%)	Wet density (g/cm^3)	Cohesion (kPa)	Internal friction angle (°)	Strength (kPa)
GRM_01	27.16	0.61	1.77	25.39	13.50	36.59
GRM_02	27.52	0.63	1.89	24.25	17.89	52.06
GRM_03	22.05	0.56	1.94	30.37	20.09	108.66
GRM_04	23.36	0.58	1.92	32.21	17.66	84.59
GRM_05	23.10	0.65	1.93	27.68	13.45	60.00
GRM_06	21.95	0.62	1.92	31.73	20.27	105.03
GRM_07	20.13	0.61	2.04	34.99	21.70	153.59
GRM_08	22.98	0.61	1.93	34.85	19.99	103.44
GRM_09	24.02	0.64	1.87	22.99	14.20	39.01
GRM_10	20.05	0.61	2.01	32.98	20.09	122.95
GRM_11	26.44	0.65	1.85	23.54	13.00	60.79
GRM_12	29.74	0.70	1.68	19.83	8.78	21.49
GRM_13	26.74	0.66	1.87	26.51	13.86	66.20
GRM_14	20.57	0.56	1.92	30.77	20.93	128.52
GRM_15	21.09	0.59	2.03	33.28	22.99	128.52
GRM_16	24.68	0.64	1.87	27.81	17.16	51.69
GRM_17	21.04	0.58	1.97	37.29	22.93	144.60
GRM_18	15.82	0.55	2.10	43.60	26.81	255.88
KS_01	17.89	0.53	2.11	38.89	25.69	214.30
KS_02	25.63	0.65	1.72	24.65	13.33	37.17
KS_03	26.31	0.66	1.82	23.88	10.85	48.55
KS_04	13.80	0.49	2.16	51.43	30.42	396.99
KS_05	26.94	0.62	1.78	25.10	15.13	47.11
KS_06	15.75	0.54	2.07	40.92	24.93	270.00
KS_07	27.36	0.69	1.86	22.45	13.53	33.73
KS_08	26.79	0.69	1.76	21.85	9.51	22.66

Sample	Water content (%)	Void ratio (%)	Wet density (g/cm^3)	Cohesion (kPa)	Internal friction angle (°)	Strength (kPa)
KS_09	26.01	0.63	1.82	24.72	13.06	50.10
KS_10	16.25	0.50	2.05	46.59	26.74	307.75
KS_11	30.42	0.67	1.71	21.95	9.78	40.15
KS_12	26.68	0.63	1.82	28.46	17.14	76.33
KS_13	26.54	0.69	1.91	25.77	12.78	53.63
KS_14	25.07	0.65	1.87	25.66	15.87	40.40
KS_15	26.49	0.67	1.80	21.60	12.72	27.63
KS_16	25.52	0.66	1.70	22.68	10.57	60.01
KS_17	27.72	0.66	1.82	25.95	13.03	47.57

4. Discussion

This 3G analysis gives answer of the Warukin claystone origin and refutes previous studies that incorrectly state that claystone of the Warukin Formation was composed by clay minerals. In fact, as in the results of this analysis, claystone of Warukin Formation is composed by clay-sized quartz minerals with a small amount of kaolinite and illite and none of montmorillonite. The Warukin claystone was from recycled orogen, from the older formations and basins. This is corroborated by the geochemical analysis which resulted that the claystone was composed by clay-sized quartz minerals. Quartz minerals have hardness of 7 in Mohs scale, thus if the quartz minerals are up to clay size, it indicates that they have undergone a long intensive process of sedimentation and transportation. The result of geochemical analysis also shows that Mg element was not found. Mg associates with basaltic rocks which have minerals appearing at the beginning of the Bowen series, denoting that they are fragile. Due to tectonic and sedimentation processes, the Mg was weathered, making it not found in the Warukin Formation. Since there is no Mg found in the Warukin Formation, it is impossible to have the montmorillonite in the Warukin Formation. The Warukin claystone contains a small amount of illite and kaolinite and none of montmorillonite. This is important information in geological engineering. The absence of Mg and the clay-sized quartz corroborates the provenance of Warukin claystone was from the recycled orogen process. The strength of Warukin claystone is relatively low at around 100 kPa with cohesion of 29% kPa and internal friction angle of around 17°.

Declarations

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Figures

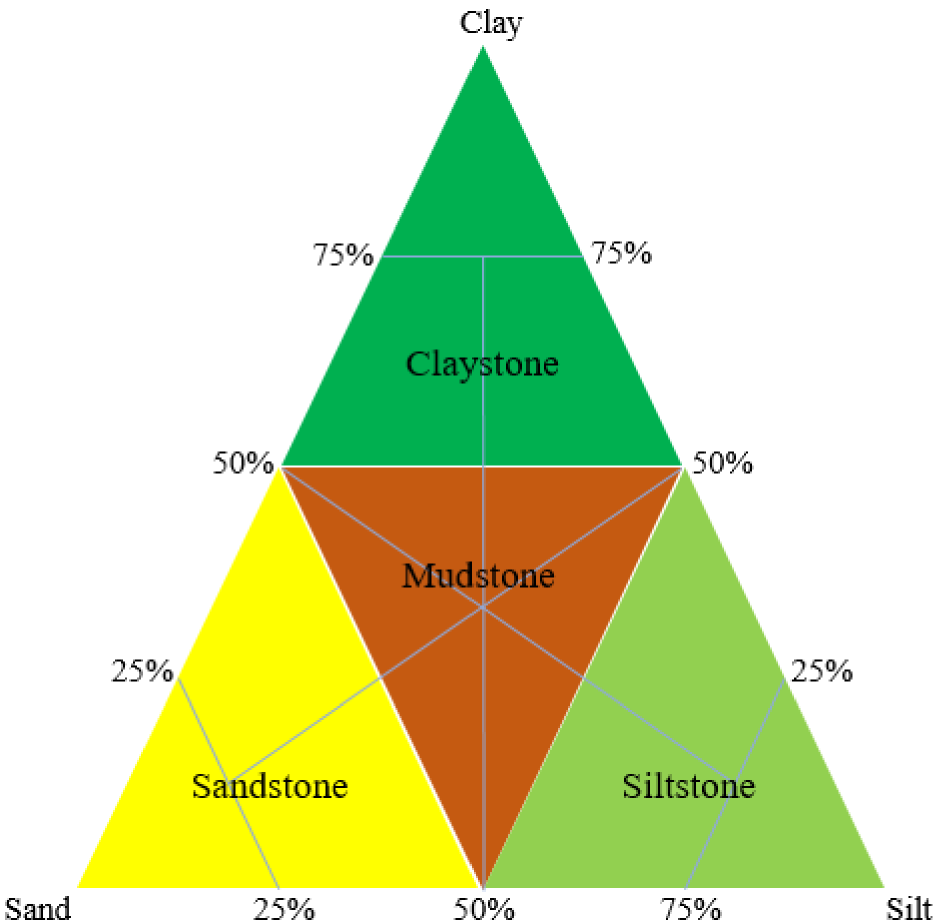

Figure 1

Definition of clastic sedimentary rock by Tucker (1996) [3].

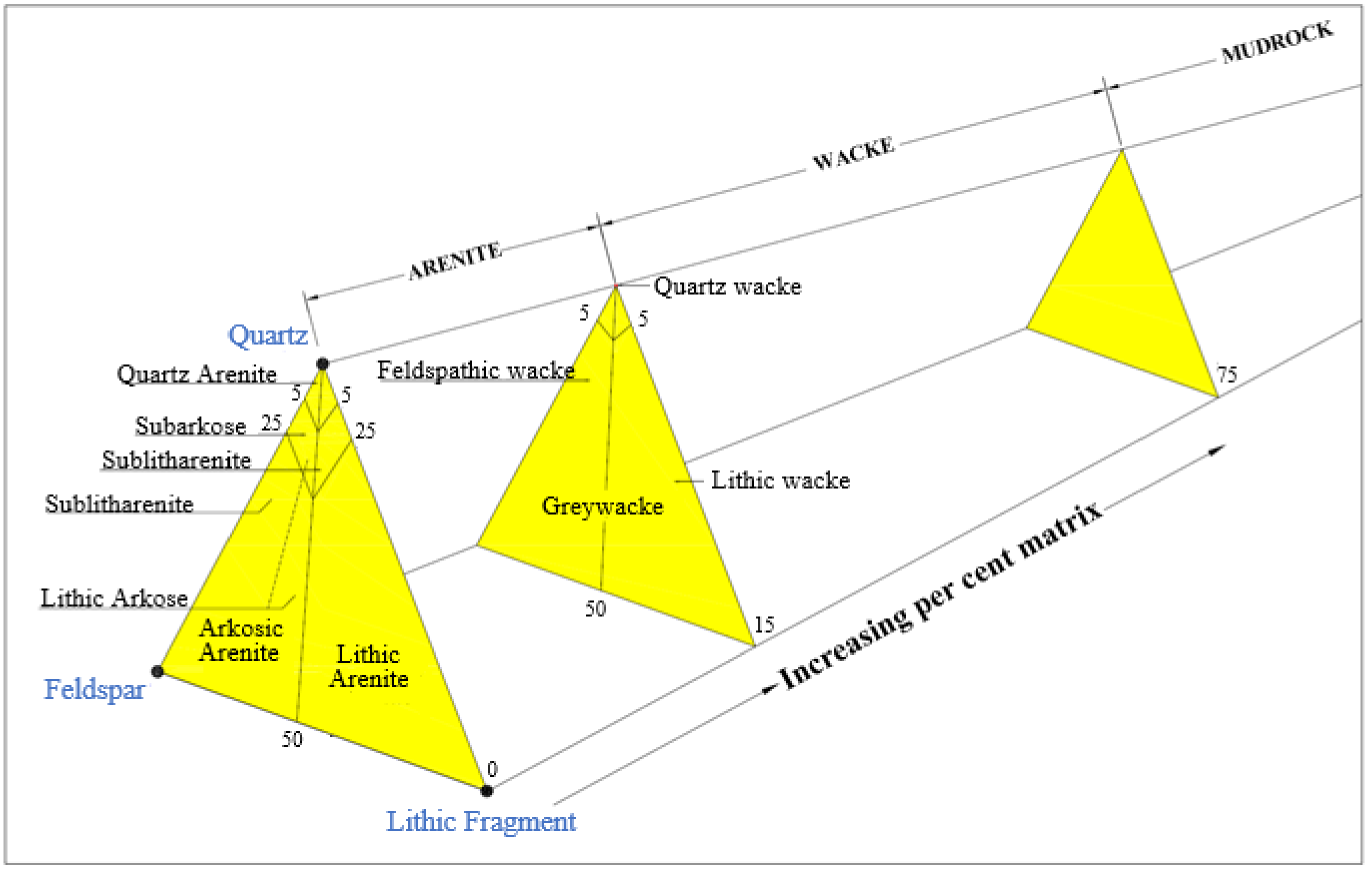

Figure 2

Classification of clastic sedimentary rock by Pettijhon (1975) [4].

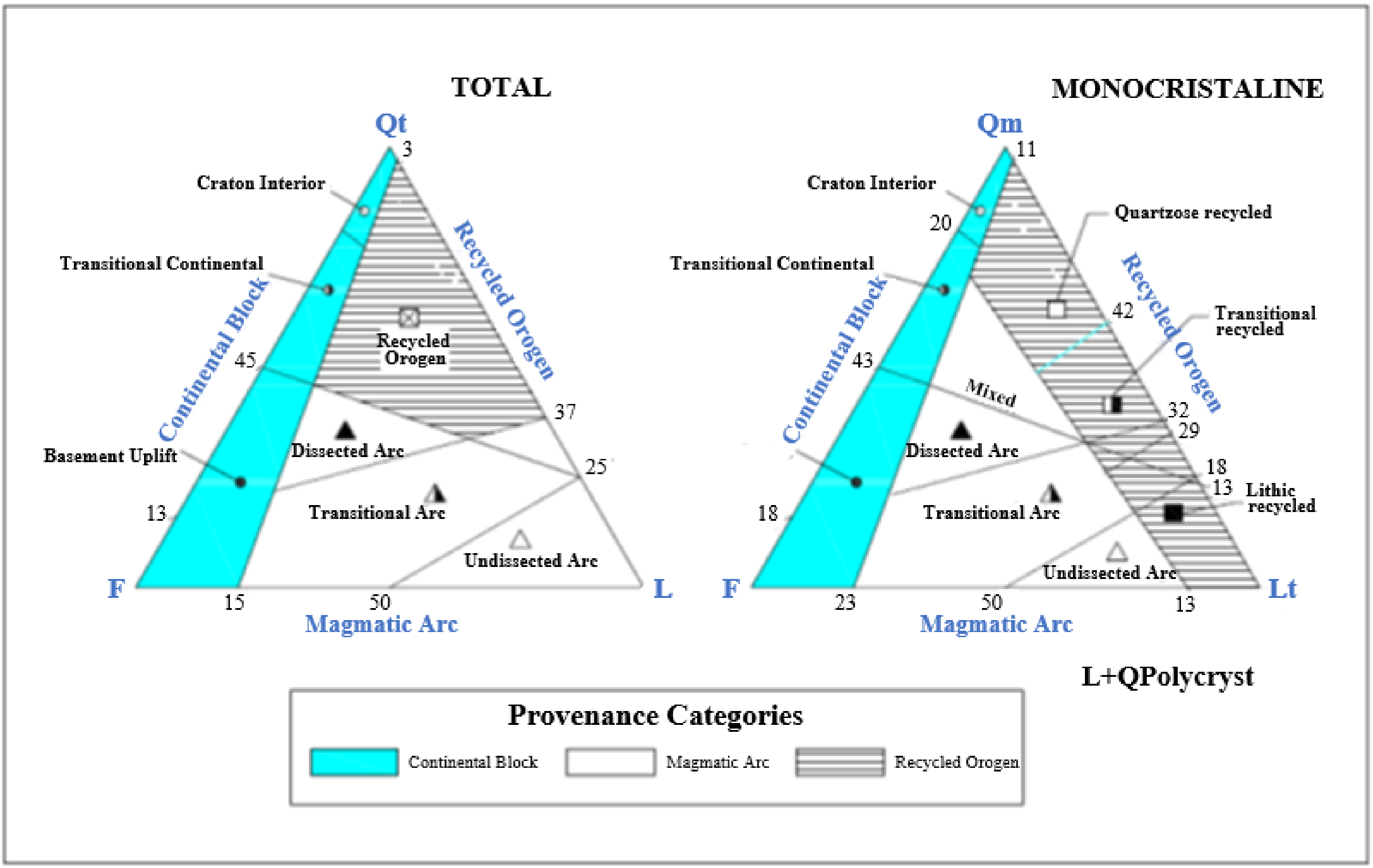

Figure 3

Classification of source rock according to Dickinson (1985) [4]..

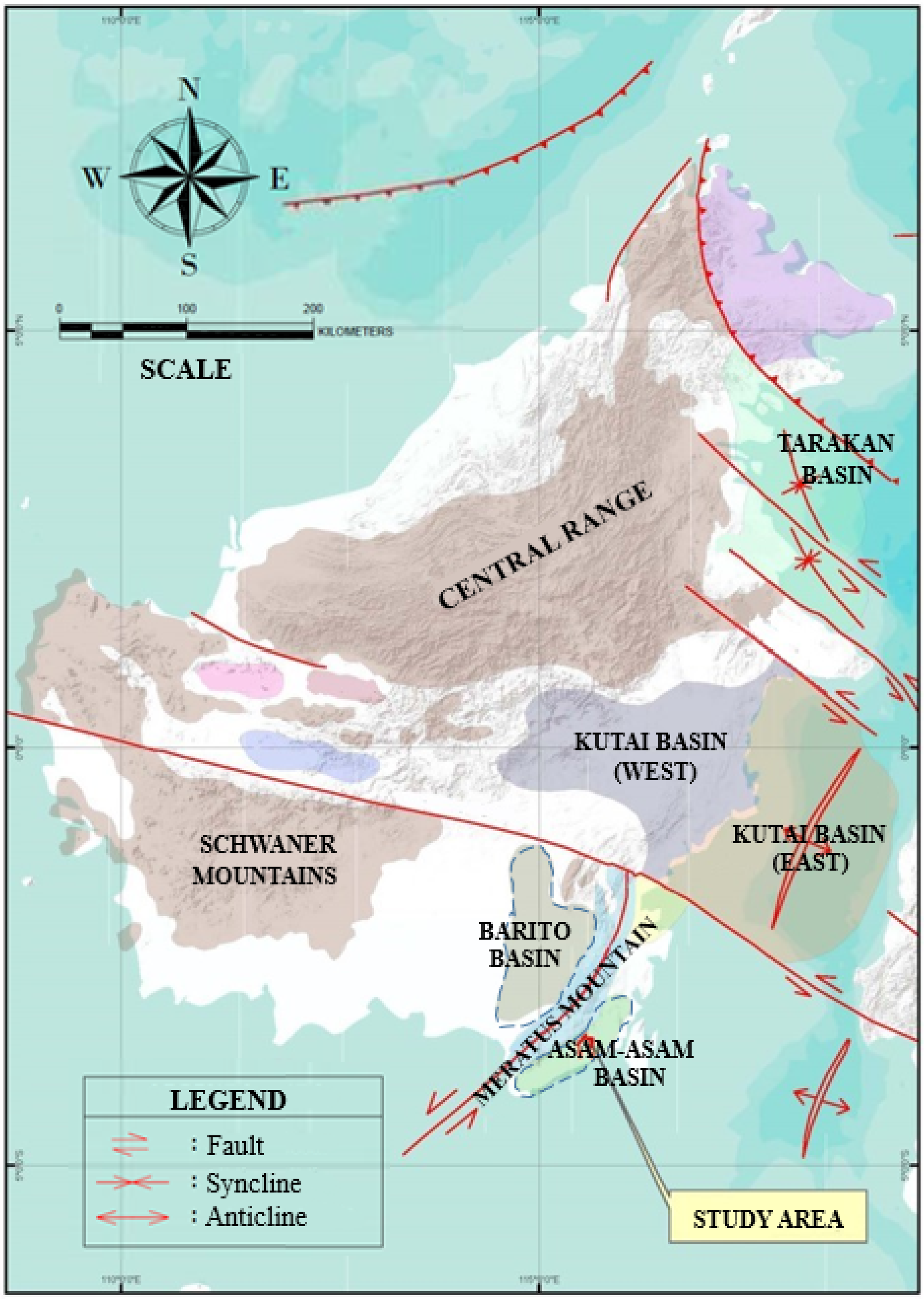

Figure 4

Regional tectonic in Kalimantan and location of the Barito Basin and the Asam-Asam Basin as study area. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

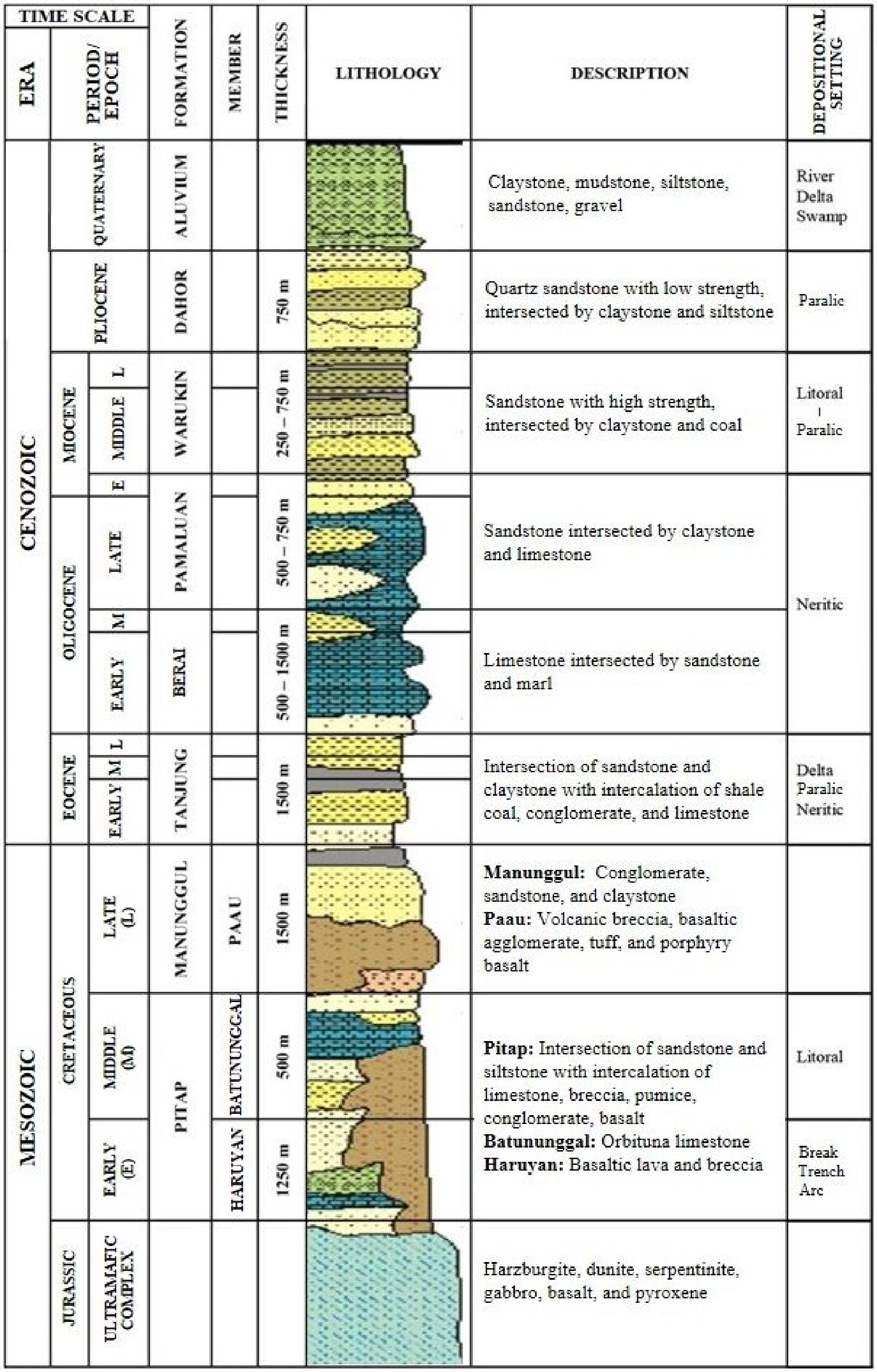

Figure 5

Regional stratigraphy of the Barito Basin (Rustandie et al., 1995) [13]. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

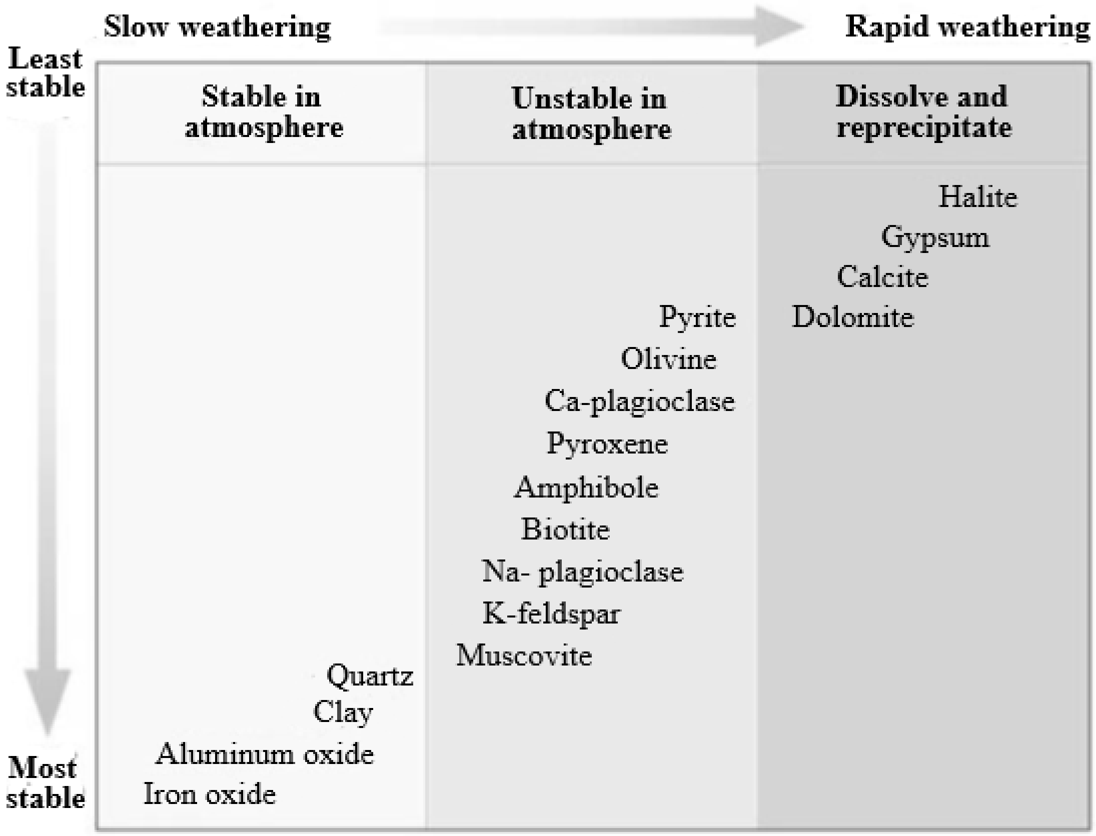

Figure 6

Goldich series (1938) [15]. shows degree of mineral resistance to weathering.

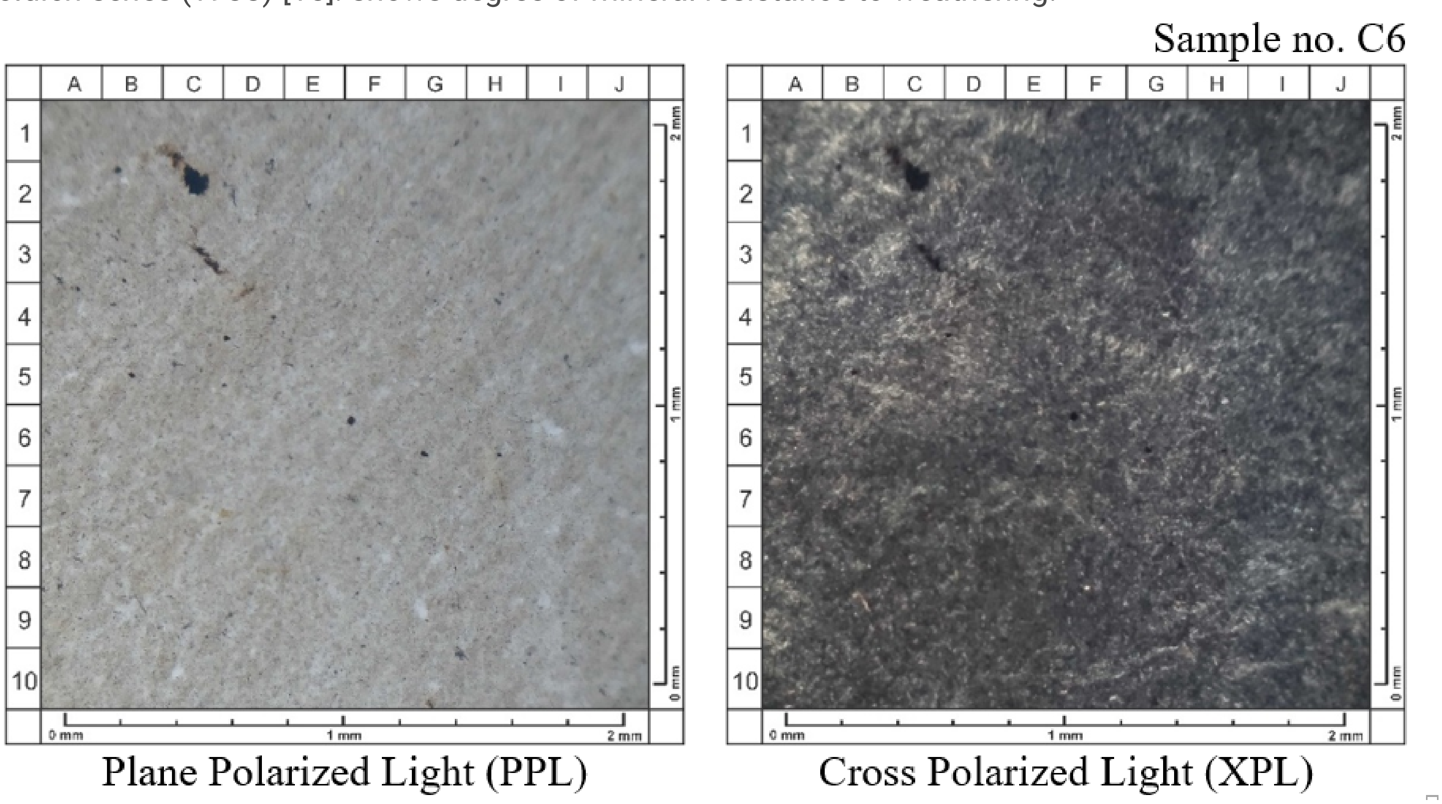

Figure 7

Appearance of Warukin claystone thin sections.

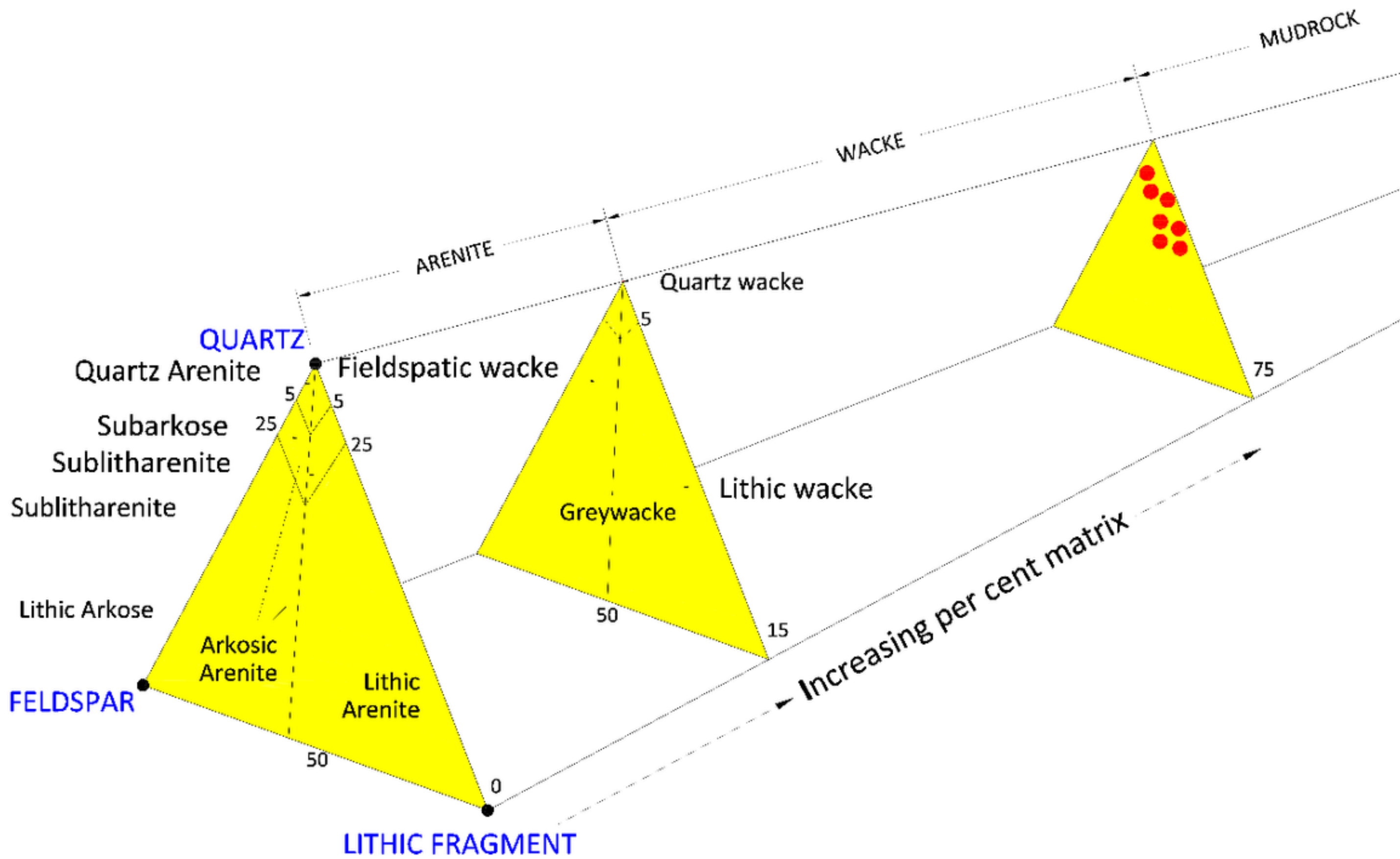

Figure 8

Classification of Warukin claystone according to the Pettijohn classification.

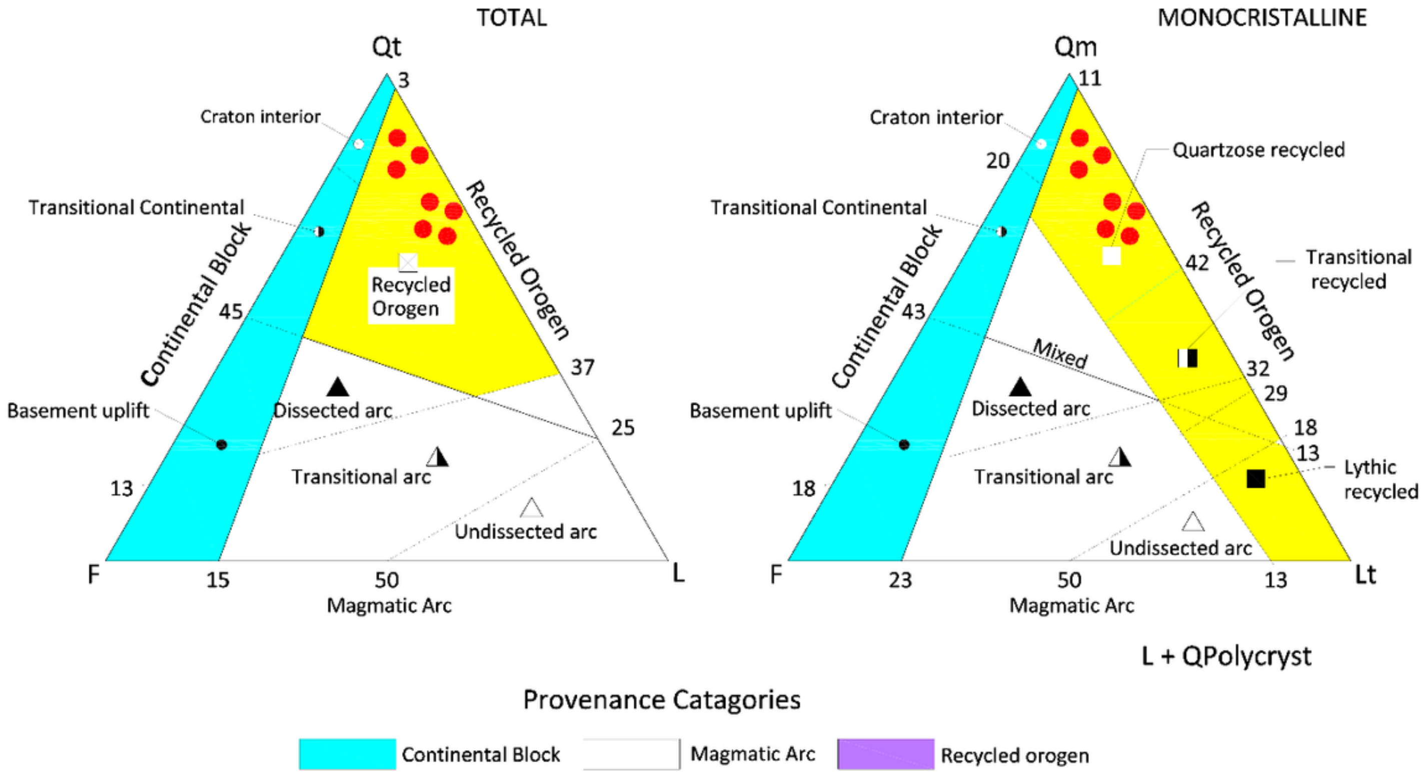

Figure 9

Provenance of Warukin claystone according to the Dickinson and Suczek classification.

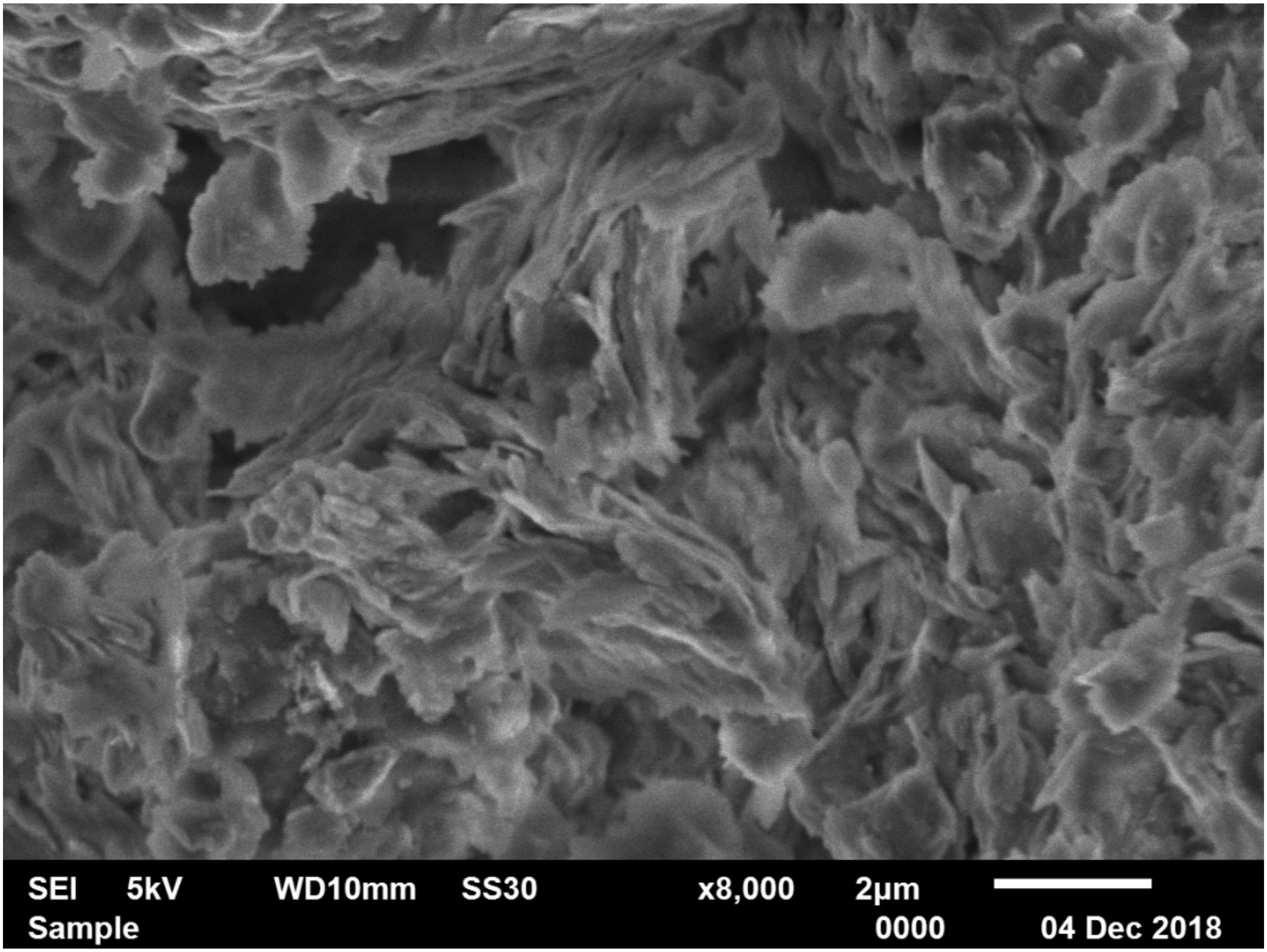

Figure 10

Scanning Electron Microscopic (SEM) result of claystone sample.