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Lithofacies and Petrogenesis of Sandstone at Kulen National Park, Siem Reap Province, Cambodia

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Abstract: *Kulen National Park is located in Siem Reap province, Cambodia, which is characterized as Jurassic-Cretaceous Sandstone formations. This study investigated eight locations of Kulen National Park area to reveal the lithofacies and petrogenesis of the Jurassic-Cretaceous Sandstone formations using 3 methods: stratigraphic measurements, petrographic analysis, and X-ray fluorescence (XRF). Fourteen sandstone samples have been selected for petrographic analysis and x-ray fluorescence (XRF). The petrography analysis provides significant information with mineral compositions, grain size, grain sorting, grain contact type, cementation and sandstone classification. X-ray fluorescence (XRF) gives the major element concentration of sandstone and define sandstone classification. The result of petrographic analysis displays dominantly of quartz in undulatory, monocrystalline and polycrystalline which accompanies by chert, plagioclase, cementing and mica groups. The sandstones are classified as "Lithicarenite and Sublitharenite". XRF result show a wide range of SiO_2 content from 49.29% to 94.47%, averaging 83.03% and vary concentrations of other major oxide elements are Al_2O_3, Fe_2O_3, CaO, TiO_2, K_2O and P_2O_5. Based on major element concentration in (wt.%) Sandstone* classified as Fe-Shale, Fe-Sand, subarkose, litharenite, sublitharenite. *Both results show dominantly of quartz among of other accompany minerals content.*

Keywords: Lithofacies, Petrogenesis, Sandstone, Mineral Composition, Kulen National Park Area

1. INTRODUCTION

The sandstone and laterite were used in the construction of the many Khmer monuments, bridges and gates, structures, as the Angkor monuments in Siem Reap Province. The masonry temples constructed by the Khmer people during the Angkor period are generally referred to as Khmer monuments, and they were built with sandstone, laterite and brick, as with the Angkor monuments. Laterite is reddish brown rock formed on the surface in wet tropical areas due to intensive weathering and is enriched in Al and Fe [1, 2]. Besides, sandstone give information derived from vary sources of sediments accumulates in different locations at Kulen National Park.

In this study, to described detail of three lithofacies at Kulen National Park area, in order to correlate with the stratigraphy measurements lithology such as, sedimentary structures (bed thickness and cross-bedding), grain size and sample selected. Besides, petrogenesis of sandstone rely on petrographic analysis to reveal mineral compositions, grain texture (size, sorting, contact type and roundedness, cementing and sandstone classification. Moreover, major oxide concentrations use chemical composition to classify the sandstone [3-6]. Geochemical analysis is a valuable tool in the study of sandstones [7, 8].

The main purpose of the present study is to investigate the lithofacies and petrogenesis of sandstone through stratigraphy log measurement, lithofacies of sandstone and the combination of petrography and geochemistry data of sedimentary rocks can reveal sandstone classification

For geological setting, Tonle sap basin is a foreland basin type, which covers an area of 23,800 km^2. It is generally occurred by tectonic activity [9]. Kulen National Park is an area located at the northern part of Tonlesap basin. This zone composes mainly of young alluvium, Jurassic-Cretaceous sandstone and Deveno-Carboniferous sandstone and shale (**Fig. 1**) structure and stratigraphy unit at the study area is located in the age of

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Mesozoic sedimentary units (Upper Triassic-Cretaceous). The Triassic in the southern part of the Indochina peninsula was marked by marine transgressions and regressions of varying length and extent. There is a general tendency for the early Triassic to be more marine in character, changing to increased continental sedimentation in the late Triassic. The Triassic was a time widespread rhyolitic volcanism in the peninsula, especially so in the middle and late Triassic time. The late Triassic is also characterized by numerous granitic intrusions. This study was selected the eight locations, such as Bat Cave (BC zone), Plov Cherng Chab (PCC zone), Perng Chen (PC zone), Preah Kral (PK zone), Perng Tbal (PT zone), Perng Tok Preah (PTP zone) Sras Domrei (SDR zone), Vat Chas (VC zone) (**Fig. 1**) for conducting measurement of stratigraphy and collecting sandstone samples to understand their lithofacies and properties.

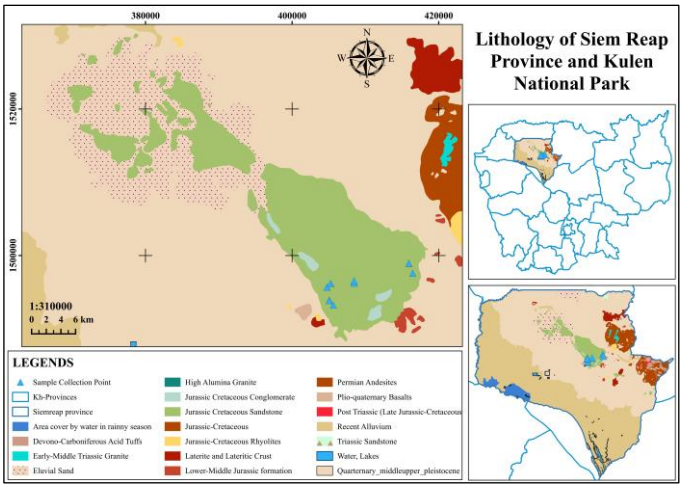


Fig. 1. Geological map of the study area. Blue triangles show fourteen samples collected at Kulen National Park area

2. METHODOLOGY

2.1 Measurement of Stratigraphic section (MS)

Measurement of stratigraphic section (MS) is a method to record rock strata, sedimentary structures, mineralogy, grain size. In this study, MS was carried out by observing and recording the character and attributes of the rock outcrop in the field. The data collection and interpretation such as lithofacies, grain size and sedimentary structures were summarized within the stratigraphic log (**Fig. 2**).

2.2 Petrography

Petrography is a method used to analyze samples by observing mineral composition, grain texture (size, sorting and contact type) and cementing under the Optical Microscope. This method provides qualitative information about mineral compositions, texture, sedimentary textures, and diagenetic processes. The thin sections of fourteen rock samples taken from the field were prepared using struers specifics resin, blue-dyed powder mixed with curing agent in the ratio 10:1. Petrographic thin sections of sandstones are conducted under Optical Microscope (Model: ECLIPSE CI-POL.B) [10].

2.3 X-Ray fluorescence (XRF)

Major oxide concentrations were determined using X-ray fluorescence (XRF) spectrometry. For this study, 14 sandstone rock samples were selected. Samples were ground into powder in agate mortar to prevent contamination. The precision of the chemical analysis is better than 10% which is observed from replicate analysis of samples and standards. Loss on ignition (LOI) was determine by weighing 1g of dried sample in the form of powered before and after heating at 950°c for 2 hours and let it could down in a suitable temperature [11].

3. RESULTS AND DISCUSSION

3.1 Lithofacies

MS is a method used to measure a vertical stratigraphic section. It provides the information of lithofacies types, thickness of lithology, geological sequence of rock strata, size and texture of rock units at Kulen National Park area. Moreover, sedimentary structures display laminated bedding and cross bedding, also shows vary grain size from fine to coarse grain (**Fig. 2**). Furthermore, 3 lithofacies of sandstone show the similarity of sandstone properties such as grain size ranging from fine to coarse grain with laminae and bedded as well. In contrast, sandy conglomerate composed medium to coarse grain rip up clast on erosional which occurred openg vugs. Another facies a conglomerate composed vary size of clast from 2mm in diameter to boulder (**Fig. 3**).

Sras Domrei (SDR)

According to the (**Fig. 2**), the lithofacies, predominantly sandstone with interbedded gravel conglomerate (angular to sub-angular). There are visible cross-bedded within the sandstone in the thickness of the middle part is around 2m, suggesting high energy deposit in a dynamic environment, likely influenced by water or wind. In line with the description of Triassic strata in comparable continental-marine environments, the presence of large-scale cross-beds may also indicate an aeolian (wind-blown) influence within the larger continental system. The dynamic, daily conditions in the old river or delta channels are thus reflected in these structures [12]. Slightly pink color, highly oxidation caused by weathering process, coarse to medium grains, and poorly sorted.

Preah Aong Thom (PAT)

The sandstone outcrop consists of a sandy conglomerate comprising a structureless (massive), thickly bedded, fine to medium-grained sandstone, poorly to moderately sorted, shows in (**Fig. 3A**). The massive structure lithofacies consists of thick beds of coarse- to medium-grained sandstone that conspicuously lack internal layering, suggesting a setting of very high-energy deposition Immaturity and quick burial are indicated by the inadequate sorting that is occasionally connected to large sandstones [12].

Peung Tbal (PT)

Sandstone in thin layer facies is defined by changes in grain size mineralogy, composition, color and can be produced in several way, in (**Fig. 3B**). Flat bedding in sandstone can be formed through deposition either from strong currents in lower phase-bed phase lamination, laminae are several millimeters thick and are made visible by subtle grain size changes. The fine-grained rock known as laminated silt lithofacies (LS) has very thin, parallel layers (laminae) of silt and clay, indicating that it was deposited in a low-energy, quiet-water environment. It could only have been deposited by suspension settling after being carried far from the main sediment source or after a current completely waned due to the extremely fine nature of the sediment [12]. Compare to the stratigraphy log measurement contain 3 separate layers that has dark red to light pink color with fine to coarse grain and laminate bedding [13], (**Fig. 2**).

Peung Ta Khok (PTK)

In (**Fig. 3 C**). expose the clasts are randomly distributed but sometimes are aligned on the bedding planes. The sizes of the clasts vary but most range from 1 cm to 7.5 cm, in rectangle range 7.5cm, the clast over 2mm of that sandstone in diameter are divided into granules, pebbles, cobbles and boulders [14].

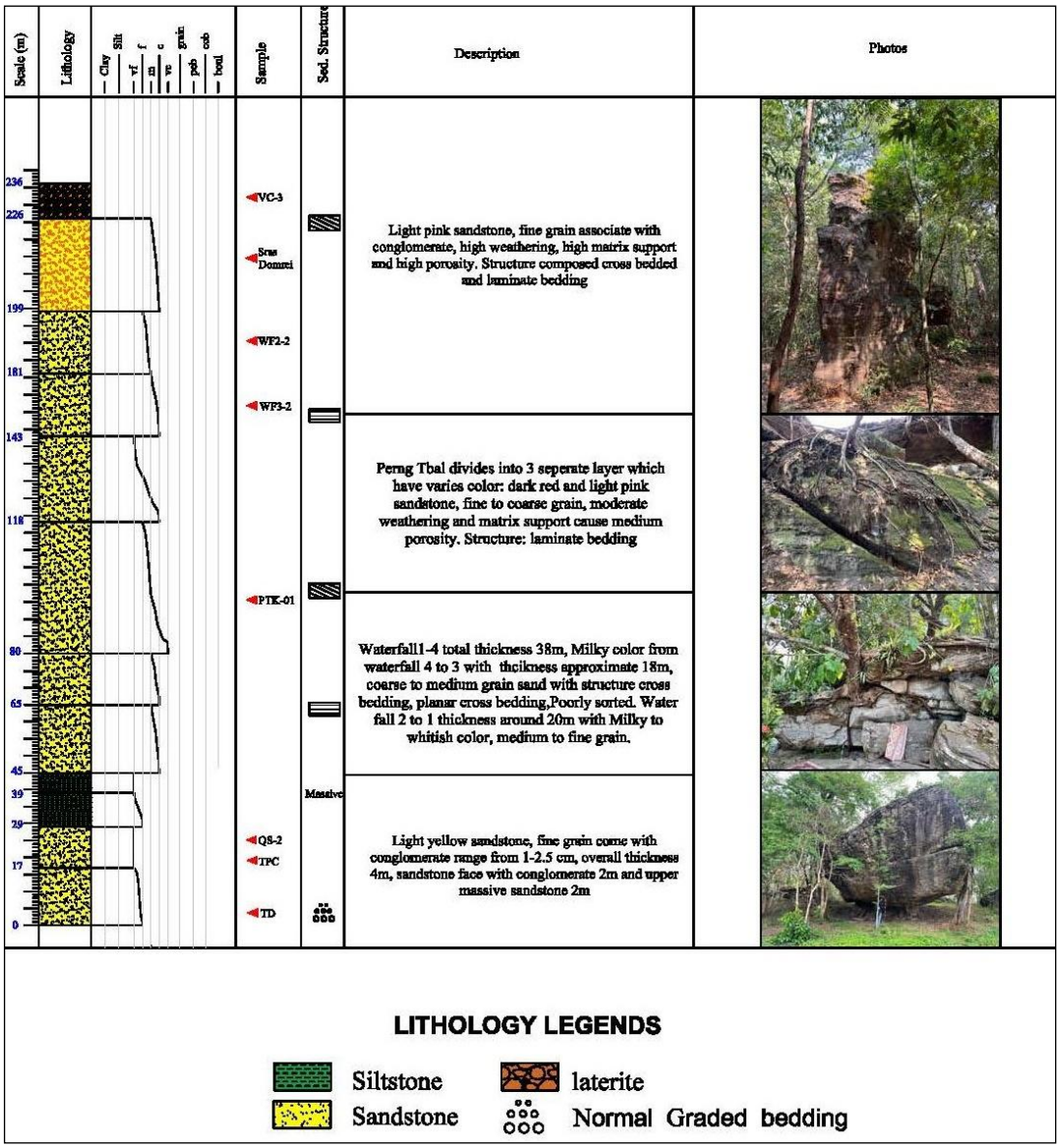


Fig. 2. Stratigraphy log of sedimentary structure at Kulen National Park

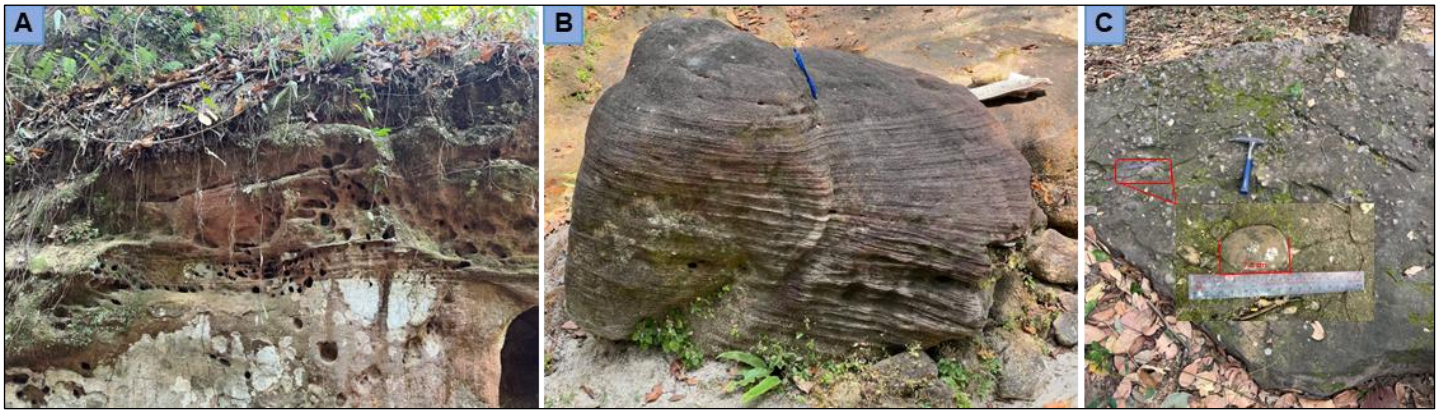


Fig. 3. A. Sandy conglomerate overlying medium to coarse grained siliceous sandstone with limestone rip-up clast on an erosional contact. This open vugs occurred due to limestone dissolution in the sandy conglomerate bed, B. Thing layering in sandstone, flat-bedding in sandstone formed from strong currents, referred to as upper plane bed phase lamination, C. A conglomerate composed of well-rounded pebbles-clast over 2mm in diameter are into granules, pebbles, cobbles and boulders

3.2 Petrographic Analysis

There are fourteen samples from eight location of Kulen National Park areas were selected to do petrographic analysis to reveal the sandstones and laterite, mineral compositions, grain texture (size, sorting, and contact types). The sandstone and laterite grain were displayed from fine to coarse-grained with fair amount of matrix. The micropetrography of sandstones and laterite of the Kulen National Park are shown in (**Fig. 4 A, B, C, D, E, & F**). The framework grains of sandstones samples are composed of monocrystalline quartz (Qm), polycrystalline quartz (Qp), undulatory monocrystalline quartz (Qu), chert (ch), plagioclase (plg), mica flake and lithic or rock fragments.

The most common framework components are quartz mineral, being primarily monocrystalline and lesser amount of polycrystalline grain. The grain shape of quartz is subrounded to subangular with mechanical fractures and on an average, monocrystalline quartz (92%), dominates over polycrystalline quartz (4%). The monocrystalline quartz grains range from sub-rounded to sub-angular in (**Fig. 4&5 C, E, G, J, & L**), whereas the polycrystalline quartz grains vary from sub-rounded to angular in (**Fig. 4&5 A, E, G, J, & K**). The grain contact types are long, concavo-convex and suture in (**Fig. 4&5 A, D, F, & H**). Mica flake has been identified in (**Fig. 4C**), Siltstone in (**Fig. 5I**), and Chert in (**Fig. 5K**) are presented in the samples

The sandstone stone classification are shown as sublitharenite for BCzone, PCC zone, PC zone, PK zone, PT zone, PTP zone, SDR zone, and litharenite for VC zone (**Fig. 6**) [10].

In this view of the abundance distribution of quartz in detrital rocks, it is not surprising that many attempts have been made to use the characters of the clastic quartz grains as indicators of the provenance and sedimentary history of a sediment. In sedimentary rocks consisting entirely of quartz, the nature of the quartz grains affords the sole means for determining such things as provenance, nature of the transporting and environment of deposition. The average quartz of sandstones lies between 60% and 70% and many sandstones are composed almost entirely of this mineral [3].

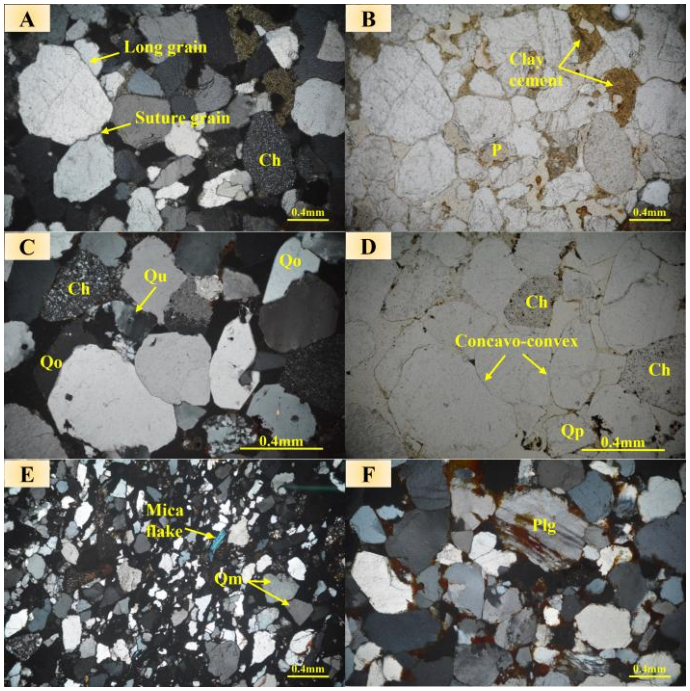


Fig. 4. Microphotographs of sandstone at Kulen National Park (G) Yellow aarow shows undulatory quartz, overgrowth quartz (Qo) and grain sorting from angular to subangular. (H) this microphotograph displays monocrystalline quartz (Qm), pore (P) and clay cement. (I) Polycrystalline quartz (Qp), monocrystalline quartz (Qm), undulatory monocrystalline quartz (Qu) and plagioclse feldspar (Plg) (J) Grain contact types; long and suture grain (K) Undulatory quartz, polycrystalline quartz (Qp) and hematite cementing (L) Monocrystalline shows mechanical fracture. Grain sorting from angular to subangular [3]

Style in Grain Compaction

The degree of compaction varies considerably, ranging from nearly non-compacted to moderately and to strongly compacted sediment [15]. The grain contact patterns gradually change from non-contact to point contacts to long contact, then to concavo-convex contact and finally sutured contact [16] (**Fig. 4 & 5**) .

In the case of more rigid grains, the mechanical compaction caused float and point contacts to become long contacts and fracturing of rigid framework components. Chemical compaction resulted in the formation of dissolution contacts which give concavo-convex and sutured grain contacts, both caused by pressure solutioning. In sandstone, long grain contacts are mostly representative of intermediate burial depth and concavo-convex and sutured contacts are as a result on intense compaction and pressure dissolution during deep burial diagenesis.

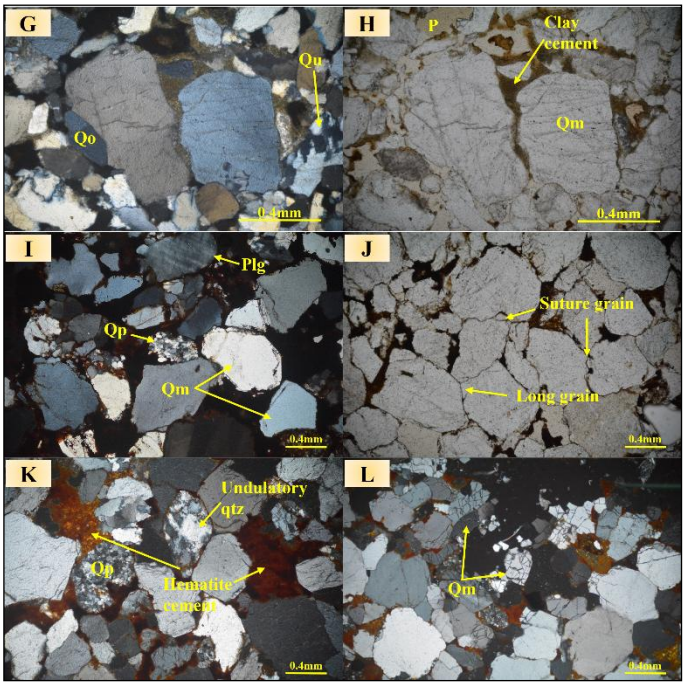


Fig. 5. Microphotographs of sandstone at Kulen National Park (G) Yellow aarow shows undulatory quartz, overgrowth quartz (Qo) and grain sorting from angular to subangular. (H) this microphotograph displays monocrystalline quartz (Qm), pore (P) and clay cement. (I) Polycrystalline quartz (Qp), monocrystalline quartz (Qm), undulatory monocrystalline quartz (Qu) and plagioclse feldspar (Plg) (J) Grain contact types; long and suture grain (K) Undulatory quartz, polycrystalline quartz (Qp) and hematite cementing (L) Monocrystalline shows mechanical fracture. Grain sorting from angular to subangular [3]

Grain Deformation and Fracturing

Grain fracturing, though not intense, was observed on some detrital quartz grains in samples from Kulen Nation Park (**Fig. 4 & 5**). Various factors affect the rock mechanical properties, including the component grains, textures, structures, porosity, permeability and pore fluids of the rocks [16]. Grain fracturing provides key evidence of the processes of compaction, consolidation and the pattern of fluid flow. Grain fracturing takes place mostly during late diagenesis and fluence by processes such as dissolution, which tends to enlarge the fractures [17], (**Fig. 4**).

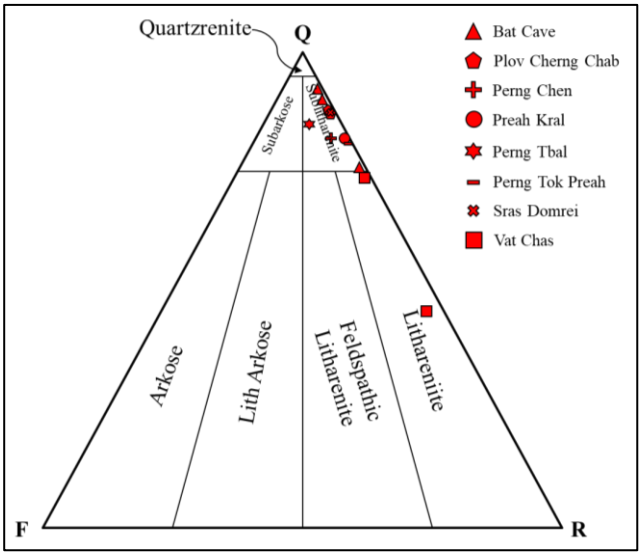


Fig. 6. Sandstone classification of 8 different zones [10]

3.3 Geochemistry of Sandstones

The major (wt.%) concentration of Jurassic sandstone is reported in (**Table 1**). The major element compositions of Jurassic sandstones are variable Higher enrichment in SiO_2 contents, 49.29-97.63%, is observed in the sandstone except for laterite sample, VC-1, 49.29%.

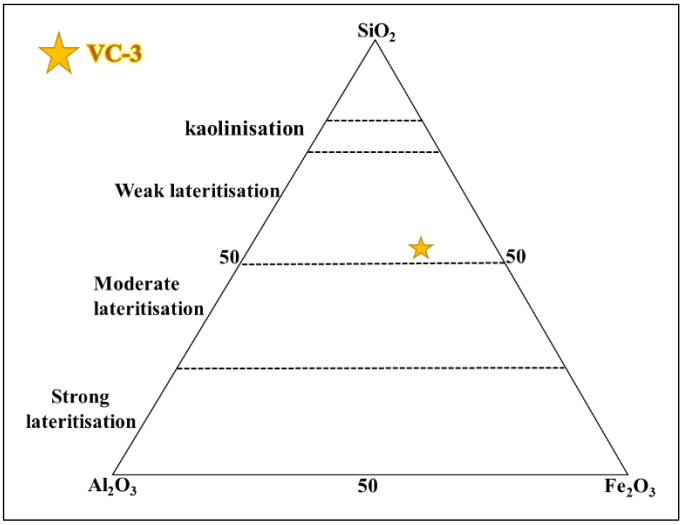


Fig. 7. Triangular diagram illustrates laterite classification [18]

Table 1. Major element concentrations (in wt. %) of sandstones at Kulen National Park, Siem Reap province, Cambodia

SAMPLE ID	SiO_2	AL_2O_3	Fe_2O_3	MgO	CaO	Na_2O	TiO_2	K_2O	MnO	P_2O_5	Total (%)	LOI	Log (Na2O/K2O)	Log (Fe2O3/K2O)	Log (SiO_2/AL_2O_3)
BCC	96.72	0.58	0.36	0.04	0.03	0.08	0.04	0.21	N/A	0.80	98.86	0.89	-0.41	0.24	2.22
BCI	84.43	3.45	8.59	0.03	0.82	0.02	0.06	0.08	N/A	0.72	98.21	2.49	-0.72	2.01	1.39
BCS	81.58	0.80	5.35	0.02	0.01	N/A	0.15	0.47	0.02	9.13	97.53	2.39	-	1.05	2.01
PCC-1B	92.99	4.84	0.09	0.03	0.02	N/A	0.10	0.08	N/A	0.03	98.17	1.76	-	0.06	1.28
PCC-1T	91.59	5.03	1.17	0.02	0.01	N/A	0.09	0.06	N/A	0.04	98.02	1.93	-	1.27	1.26
PCC-3	97.63	1.45	0.29	0.02	0.08	0.02	0.06	0.03	N/A	0.03	99.60	0.30	-0.11	1.05	1.83
PC	92.55	5.31	0.44	0.03	0.01	0.01	0.05	0.08	N/A	0.02	98.49	1.46	-0.79	0.75	1.24
PK-2	94.47	4.10	0.21	0.02	0.01	N/A	0.08	0.05	N/A	0.06	98.99	0.96	-	0.65	1.36
PK-1	94.28	3.78	0.31	N/A	0.02	N/A	0.04	0.05	N/A	0.05	98.52	1.42	-	0.81	1.40
PT-2B	94.15	4.63	0.10	0.05	0.02	0.05	0.12	0.12	N/A	0.03	99.26	0.65	-0.38	-0.08	1.31
PTP-2T	90.76	6.32	0.90	0.14	0.03	0.02	0.09	0.39	N/A	0.08	98.73	1.19	-1.27	0.36	1.16
SDR	90.69	2.88	4.67	N/A	0.01	N/A	0.08	0.03	N/A	0.15	98.50	1.41	-	2.20	1.50
VC-1	86.81	8.65	1.17	0.19	0.02	0.03	0.17	0.68	N/A	0.07	97.80	2.14	-1.41	0.23	1.00
VC-3	49.29	13.52	29.94	0.13	0.02	0.02	0.30	0.44	0.02	0.14	93.82	5.94	-1.30	1.83	0.56

The low concentrations of Fe_2O_3 and TiO_2 in the sandstones reflects the low abundance of Ti-bearing minerals such as biotite, ilmenite, titanite, and titaniferous magnetite [19]. Generally, Na_2O and K_2O are controlled by feldspars and the depletion in these oxides suggests the destruction of feldspars, due to the source area or during transportation.

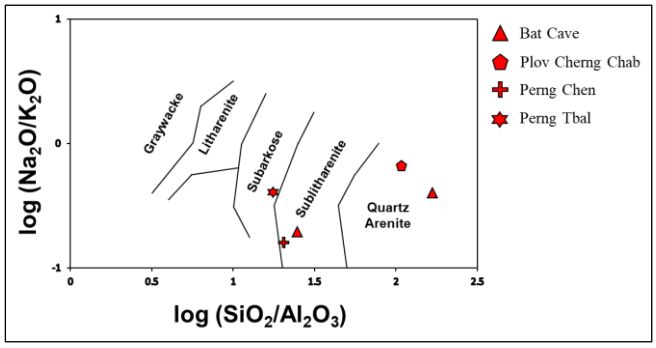


Fig. 8. Chemical classification of Jurassic sandstones, [4, 14]

Based on the classification diagram [4], the Jurassic sandstones are classified as subarkose, sublitharenite and quartzarenite (**Fig. 8**) and according to [11] are classified to Fe-Shale, Fe-Sand, litharenite, sublitharenite, subarkose and quartzarenite (**Fig. 9**). No clear trend for discrimination of the sandstones from the different Kulen National Park area, this may be attributed to the variations of the major elements within the formation. Since, VC-3 is a laterite after plotted into the triangular diagram show as a weak lateritisation (**Fig. 7**)

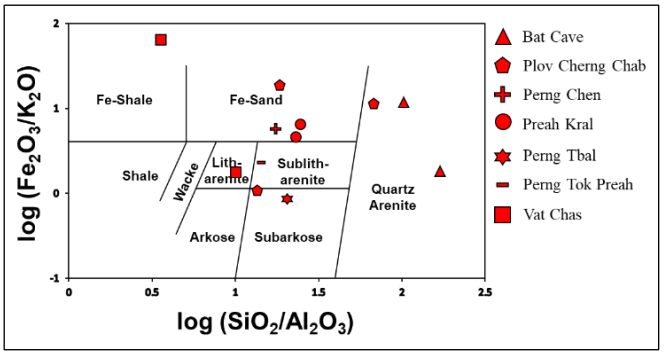


Fig. 9. Chemical classification of Jurassic sandstones, [11]

4. CONCLUSIONS

The stratigraphic measurement of outcrops and petrographic analysis of sandstones at Kulen National Park area show different types of lithofacies, sedimentary structures, grain texture (size, sorting and contact type), mineral compositions, sandstone classification:

Three lithofacies at Kulen National Park, Sandy conglomerate open vugs, flat bedding sandstone formed from strong current and outcrop of sandstone with conglomerate in varies clast size, thin layer or flat bedding formed by strong currents, referred an upper plane bad phase lamination, and conglomerate composed well rounded pebbles clast over 2mm. The Jurassic sandstones can be classified as litharenite and sublitharenite based on petrographic analysis and Fe-Shale Fe-Sand, subarkose, litharenite, sublitharenite based on major element geochemistry and dominantly consists of quartz (49.29-97.63%), very little feldspar and lithic fragments and necessary minerals

The diagenetic process includes style in grain compaction occurred as concavo-convex, suture and long contact are result in intense compaction and pressure dissolution during deep burial diagenesis. Sandstone mainly composed of quartz (occurred as undulatory, monocrystalline and polycrystalline) accompany by feldspar, plagioclase, chert

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