Sediment Transport Mechanism and Provenance of Unconsolidated Sediments in Opak River Channel, Yogyakarta, Indonesia

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Abstrak- Penelitian ini difokuskan pada Sungai Opak yang secara administratif melintasi 2 kabupaten, yaitu Kabupaten Sleman dan Kabupaten Bantul. Tujuan dari penelitian ini adalah untuk mengetahui mekanisme sedimentasi dan *provenance* sedimen Sungai Opak berdasarkan komposisi dan tekstur detrital sedimen. Sampel sedimen diambil dari tubuh alur Sungai Opak dari hulu hingga hilir, yaitu sebanyak 10 titik pengamatan. Analisis yang dilakukan adalah analisis granulometri, analisis morfologi butiran, kemudian dilanjutkan dengan analisis QFL yang mana proporsi detrital mineral ringan dihitung (kuarsa, feldspar, lithik). Tekstur sedimen *channel* Sungai Opak adalah rata-rata pasir berbutir kasar, tersortasi buruk, kelas *sphericity intermediate to subequant*, dan derajat kebundaran dari menyudut hingga membundar tanggung. Secara komposisi, sedimen Sungai Opak bertipe *arkose - lithic Arkose* dengan rata-rata didominasi mineral ringan Feldspar (20-48%), Kuarsa (4-17,9%) dan Litik (13,5-19,6%). Mekanisme proses sedimentasi pada Sungai Opak didominasi oleh proses traksi yang dicirikan dengan persen traksi sebesar 48-79% pada kurva log probabilitas. Dari analisis QFL maka disimpulkan bahwa sedimen alur sungai terbentuk dari batuan dengan setting tektonik *magmatic arc*, subtipe *transitional arc* dengan sumber sedimen kemungkin berasal dari batuan volkanik kuarter dari Gunung Merapi atau batuan volkanik yang lebih tua (Formasi Semilir atau Formasi Nglanggran) dengan pengaruh dari Sungai Oyo, terutama di bagian Tengah hingga hilir Sungai Opak diindikasikan oleh keberadaan butiran karbonat.

Kata kunci: Asal Sumber Sedimen, Sungai Opak, Transportasi Sedimen, Traksi.

Abstract – *This study focuses on the Opak River, which crosses administratively through two regencies, Sleman and Bantul. This research aims to reveal the sedimentation mechanism and provenance of Opak River sediment based on textural and sedimentary composition. Sediment samples were collected from ten points along the river channel, spanning from upstream to downstream. Granulometric and grain morphology analysis were conducted which the followed by QFL analysis wherein the presence of light detrital minerals (quartz, feldspar, lithic) was observed. The sediment texture of Opak River Channel generally consists of coarse-grained sand, poorly sorted, with varying degrees of roundness and sphericity, which are angular to sub-rounded and intermediate to sub-equant, respectively. Opak River sediment predominantly comprises Feldspar (20-48%), Quartz (4-17,9%) and Lithic (13,5-19,6%) which implies arkose-lithic arkose type. The sedimentation process in Opak River is mainly driven by the traction process, which is indicated by a 48-79% traction fraction on the probability log curve. Based on QFL analysis, it is inferred that the Opak River sediment originated tectonically derived from a magmatic arc setting, specifically a transitional arc subtype. The primary sediment source could have been derived from quaternary volcanic rock (Mount Merapi) or older volcanic rock (Semilir Formation or Nglanggran Formation) with a potentially strong influence of the Oyo River, especially in the medial to distal part of Opak River indicated by the occurrence of carbonate grains.*

Keywords: *Provenance, Opak River, Sediment Transport, Traction.*

INTRODUCTION

The texture and composition of sediment particles are fundamental elements in sedimentary rock studies. Sedimentary texture includes all features associated with sediment grains, e.g. their grain size, shape and sortation (Dickinson, 1985). By analyzing sediment texture, one can interpret the process, especially those involving transportation and deposition. Moreover, the analysis may help to identify the depositional environment. Granulometry, the study of sediment particle size distribution, constitutes a fundamental aspect of sedimentology. This discipline encompasses various analytical

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methodologies to precisely quantify particle size and elucidate their distribution within sediment samples. This analysis provides critical insights for the energy and dynamics of depositional environment.

This study focuses on the textural and composition element of Opak River channel sediment to understand the dominant transport mode and its provenance (Figure 1). Opak River flows covers extensive area of Yogyakarta. It flows from Mount Merapi into the Indian Ocean in the south. The river runs upon Opak tectonic fault, a major tectonic fault in Yogyakarta, responsible for major earthquake in the region (Prasetyadi et al., 2016). Several studies have been conducted in the area (i.e. Setiawan, 1999; Sitinjak, 2008; Wardhana, 2015). However, possible different result may exist considering the dynamic of Opak River. Thus, this study is conducted to supply additional references on the behavior of Opak River observed in May 2016.

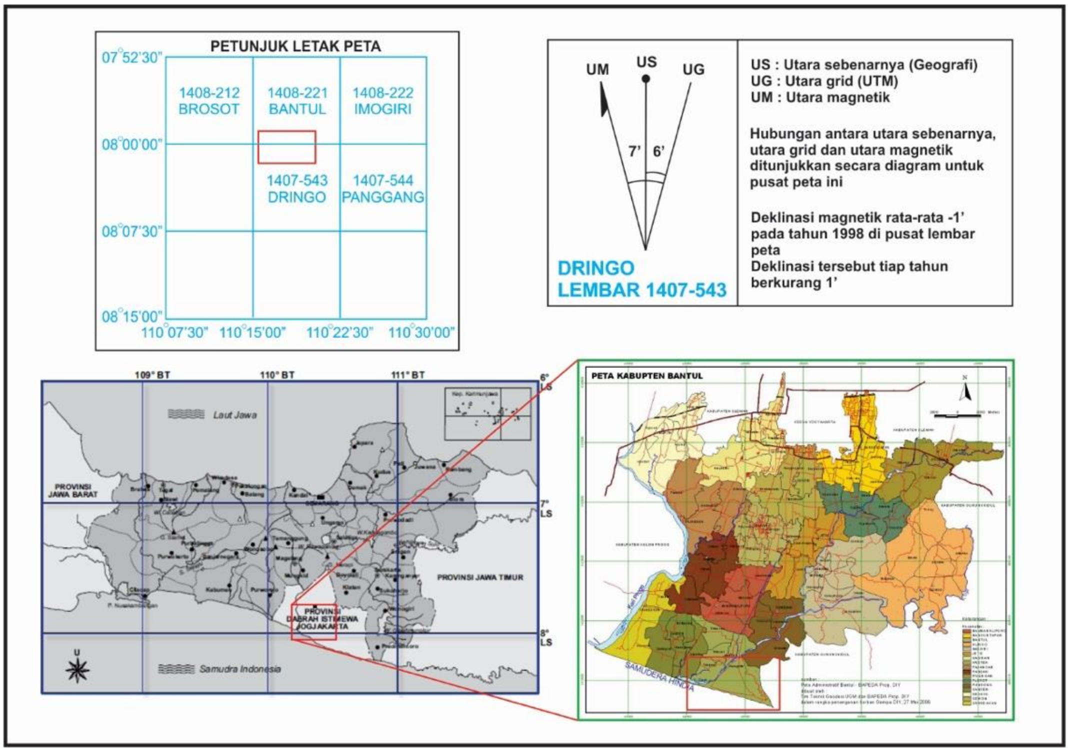

Figure 1. Research area is shown in the red box.

Regional Geology

Physiographically, the research area is in Southern Mountain Zone. Geology formation that is associated with Opak River is quaternary volcanic deposit, Semilir Formation, Nglanggran Formation, Sambipitu Formation and Oyo Formation. The relationship between geological formation in Southern Mountain Zone is shown in Figure 2. Semilir Formation comprised of volcanic rock, such as tuff, lapilli tuff, lapilli, breccia which was deposited in turbidite system. Surono et al. (1992) argued that Semilir Formation is interfingering with Nglanggran and Oyo Formation. Semilir Formation is considered as volcanic eruption product which may have been associated with phreatic explosion (Bronto and Mulyaningsih, 2001). Nglanggran Formation consists of volcanic breccia, agglomerate, tuff and basalt-andesitic lava. Volcanic breccia and agglomerates predominate this formation. The age of this formation is early Miocene.

Sambipitu Formation can be divided into two sedimentary sequences: the lower part and the upper part. Sambipitu Formation comprised of coarse sandstone in the lower part, which gradually becomes finer with intercalation of sandstone and siltstone/claystone. Volcanic component dominates the lower part and gradually carbonate materials dominate in the upper part. Oyo formation overlain Semilir Formation, Nglanggran Formation and Sambipitu Formation. The lower part of Oyo Formation consists of tuf and marl, while the upper part is dominated by calcarenite intercalating with calcareous claystone.

In Southern Mountain Zone, the structure is dominated by northeast-southwest structure (Meratus trend), north-east (Sunda trend) with minor west-east structure (Java trend). Most of the northeast-southwest structure is sinistral strikeslip fault and in some parts may have been reactivated as normal fault. These structure that have Meratus trend in Southern Mountain Zone is interpreted to be the oldest structure which may have been formed due to cretaceous subduction (Prasetyadi, et al., 2011). Opak river northeast-southwest direction is suggested to have the same structural trend with Meratus pattern. Opak fault is an active fault that can trigger earthquake if reactivated. It may have been formed due to the strain and shortening on the direction of the largest normal strain axis (Prasetyadi et al., 2016).

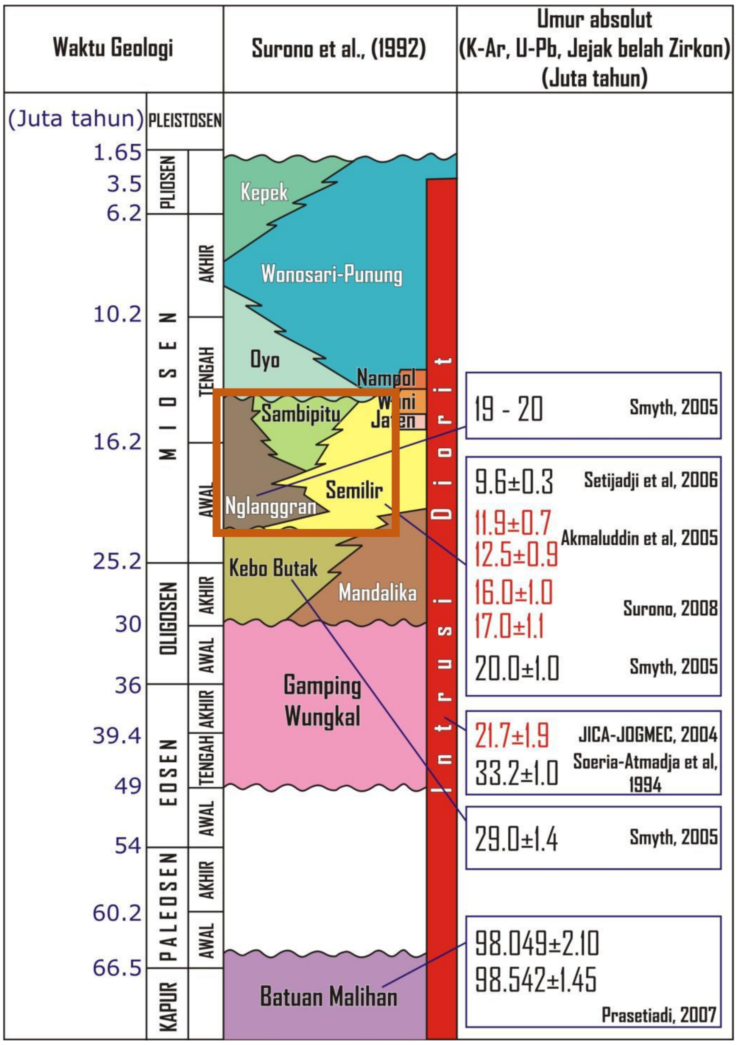

Figure 2. Stratigraphy of Southern Mountain Zone in Yogyakarta. Orange box indicates main geologic formation that is associated with Opak River (Surono et al., 1992).

METHODOLOGY

Granulometric Analysis

Sediment samples were taken from ten observation points along the Opak River channel (Figure 5). The samples were taken to the lab and dried in oven. To ensure representative sampling, a method known as splitting is employed. In this procedure, the dried detrital sample is poured into a funnel positioned above a crossed cardboard, which divides the sample into four quadrants. Samples are collected from two opposing quadrants, while the remaining two are remixed. This procedure is repeated three times until the sample weight reaches 100 grams. Following this, the sample undergoes sieving using a series of sequentially numbered sieves: #8 (2,36 mm), #16 (1,18 mm), #30 (600 μm), #50 (300 μm), #100 (150 μm), #200 (75 μm) mesh and the bottom pan. Each pan represents Wentworth scale, which are granule (sieve #8), very coarse sand (sieve #16), coarse sand (sieve #30), medium sand (sieve #50), fine sand (sieve #100) and very fine sand (sieve #200).

Each sample is sieved for approximately 10-15 minutes to separate the detrital sediment into size-specific fractions. Subsequentially, each grain size fraction is weighed, with the assumption that the sample's weight loss does not exceed 0,02% of the initial weight.

Mathematical approach based on Boggs (1987) were performed on each sediment samples (Figure 3). Skewness and kurtosis class was based on Folk (1974) shown in Table 1 and 2. A complete frequency distribution data set, including pan fraction data, is required with a margin of error of less than 0,02 grams. This assumes that the total sediment particles on the sieve weigh 100 grams, as the calculation assuming a normal distribution.

Mean
(1st moment)

$$\bar{x}_\phi = \frac{\Sigma f m}{n} \quad (1)$$

Standard deviation
(2nd moment)

$$\sigma_\phi = \sqrt{\frac{\Sigma f (m - \bar{x}_\phi)^2}{100}} \quad (2)$$

Skewness
(3rd moment)

$$Sk_\phi = \frac{\Sigma f (m - \bar{x}_\phi)^3}{100\sigma_\phi^3} \quad (3)$$

Kurtosis
(4th moment)

$$K_\phi = \frac{\Sigma f (m - \bar{x}_\phi)^4}{100\sigma_\phi^4} \quad (4)$$

Figure 3. Mathematical formula used in granulometric analysis based on Boggs (1987).

Table 1. Skewness and class interval (Folk, 1974)

Skewness Class	Mathematical Measures
Very Fine Skewed	> +0,30
Fine Skewed	+ 0,30 to +0,10
Symmetrical	+ 0,10 to - 0,10
Coarse Skewed	- 0,1 to - 0,30
Very Coarse Skewed	< -0,3

Table 2. Kurtosis and class interval (Folk, 1974)

Kurtosis Class	Mathematical Measures
Very Platykurtic	<1,7
Platykurtic	1,7 - 2,55
Mesokurtic	2,55-3,7
Leptokurtic	3,7-7,4
Very Leptokurtic	>7,4

Grain Morphology Analysis

Grain morphology analysis was conducted on the detrital sediment samples with a #50-mesh size that had been cleaned using hydrogen peroxide (H_2O_2) by soaking them for 24 hours. This procedure aims to remove contaminants adhering to the sediment grains. The samples were then dried in an open air. Observations on the dried samples were performed using a binocular microscope with an 8x magnification. The observed detrital sediments included quartz, feldspar, and lithic fragments. At each sample location, approximately 30 grains of each mineral were examined to determine sphericity and roundness.

The observation of sphericity was conducted by comparing the identified minerals with the visual comparator by Rittenhouse (1943) (Figure 4a), after which each value obtained was converted using the sphericity classification by Folk (1968) (Table 3) to determine the class of each mineral. Roundness was similarly performed on the previously identified

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minerals. The shape of the minerals was visually compared under a microscope with the visual roundness scale by Powers (1953) (Figure 4b).

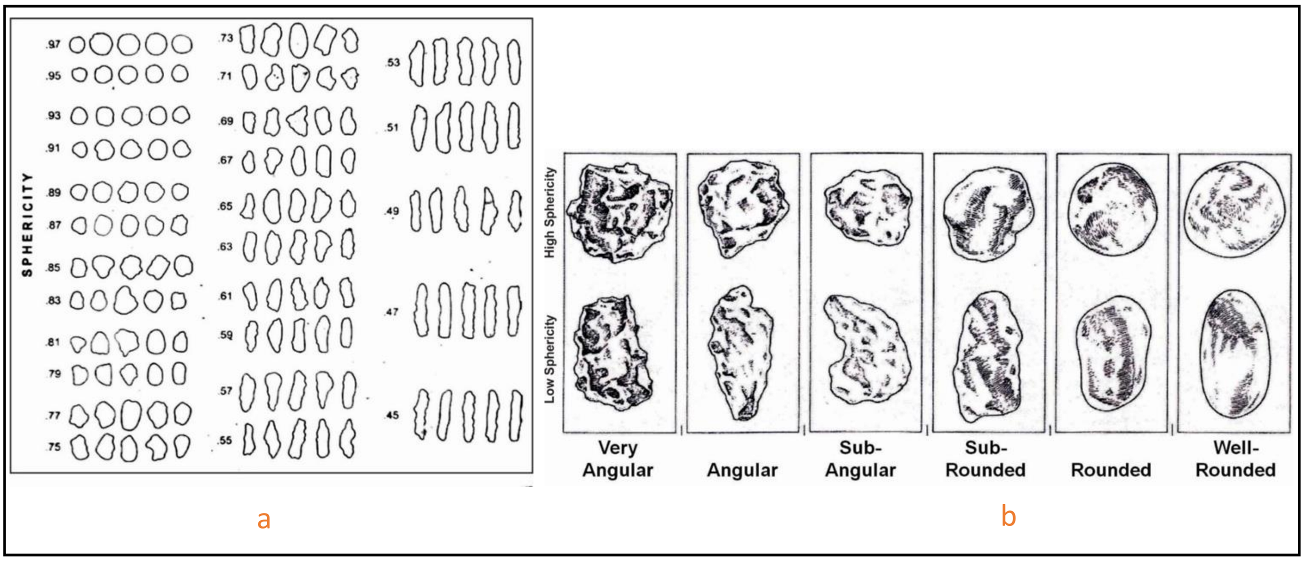

Figure 4. Visual grain comparator used for grain morphology. (a) Grain sphericity visual comparator based on Rittenhouse (1943) (b) Grain roundness visual comparator based on Power (1953)

Table 3. Sphericity class based on Folk (1968)

Sphericity index	Sphericity class
0,6	Very elongate
0,6-0,63	Elongate
0,63-0,66	Subelongate
0,66-0,69	Intermediate shape
0,69-0,72	Subequant
0,72-0,75	Equant
>0,75	Very equant

RESULTS AND DISCUSSIONS

Sediment sampling was carried out along the Opak River Channel extending from the upper slopes of Mount Merapi to the vicinity of the Opak River mouth near Depok Beach. The estimated distance between sampling sites is 5 to 7 km, encompassing 10 observation points (Figure 5). The analysis was derived from the weight coefficients of each grain size fraction. Mathematical approach of Boggs (1987) was then performed to calculate the mean, sorting, skewness and kurtosis values. The result of those calculation is summarized in Table 4.

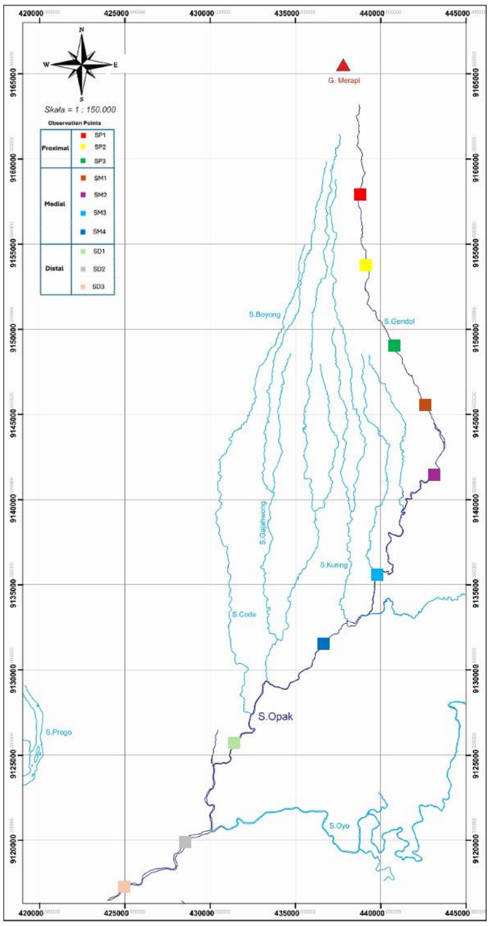

Figure 5. Sediment sample locations.

Table 4. Summary of granulometry and grain morphology analysis

Samples	Opak River Zone	Grain Size and Sorting				Grain Shape (Quartz)		
		Mean (ϕ)	Skewness	Kurtosis	Standar Deviation	Sphericity	Quantitative Measurement	Roundness
SD3	Distal	0,812	0,57	2,87	1,058	Subequant	0,715	Subangular-Subrounded
SD2	Distal	0,727	0,468	2,844	1,207	Subequant	0,7	Subangular
SD1	Distal	0,628	0,476	2,971	1,16	Subequant	0,695	Subangular-Subrounded
SM4	Medial	0,514	0,735	2,747	1,035	Subequant	0,698	Subangular
SM3	Medial	0,844	0,33	2,579	1,072	Subequant	0,706	Subangular
SM2	Medial	0,706	0,332	2,442	1,015	Subequant	0,703	Angular-Subangular
SM1	Medial	0,655	0,548	2,628	1,057	Subequant	0,686	Angular-Subangular
SP3	Proximal	0,66	0,66	2,638	1,132	Subequant	0,686	Angular
SP2	Proximal	0,676	0,855	2,884	1,223	Intermediate-Subequant	0,69	Angular
SP1	Proximal	0,394	1,09	2,936	1,35	Intermediate	0,683	Angular
Max		0.844	1,09	2,97	1,35	-	0,715	-
Min		0.394	0,33	2,44	1,015	-	0,683	-
Mean		0,662	0,606	2,75	1,131	-	0,696	-

Textural Characteristics of Opak River Channel Sediment

Grain Size

The Opak River channel sediment are coarse grained which ranges from 0,394-0,844 ϕ. The sediment average grain size is 0,662 ϕ. The grain size of samples which are located in proximal of the river show lower values than the distal part of the river **(Figure 6)**. It implies the decreasing grain size downstream.

The skewness analysis of the sediment samples shows all positive skewness value. The skewness class of all samples fell into strongly fine skew. Positively or fine skewed suggest an excess fine particle of the population. Skewness of the sediment sample may vary towards downstream but overall trend is decreasing. The decreasing value toward distal part of the river (**Table 4**) coincides with significant increase in the proportion of very coarse sand and granule (**Table 5**). This may be due to the influx of tributaries (i.e. Gajahwong River, Code River, Kuning River) supplying sediment to the Opak River. Some samples may show a little increase on the skewness value which is interpreted to have less coarse material (i.e. SM3 to SM4), especially a decrease in medium sand portion (**Table 5**). This may suggest Kuning River transported more fine and very fine sand supplying Opak River that may affect the grain proportion of SM 4.

Table 5. Grain size proportion in all observation points.

Grains size	Percentage of grains (%)									
	SD3	SD2	SD1	SM4	SM3	SM2	SM1	SP3	SP2	SP1
Granule	7,77	8,57	9,34	11,58	3,68	3,89	0,63	0,71	0,51	0,81
Very coarse sand	12,89	14,53	15,33	22,46	15,43	17,44	0,77	0,80	0,90	1,03
Coarse sand	31,68	30,35	33,35	30,38	29,94	33,88	25.66	1,01	27.78	28.78
Medium sand	30,86	32,31	30,59	22,67	36,65	27,00	24.98	0,84	0,86	0,70
Fine sand	10,63	11,18	9,83	10,19	10,57	0,65	0,59	0,65	0,46	0,34
Very fine sand	5,93	2,61	1,18	2,05	2,87	0,04	0,13	0,18	0,19	0,11

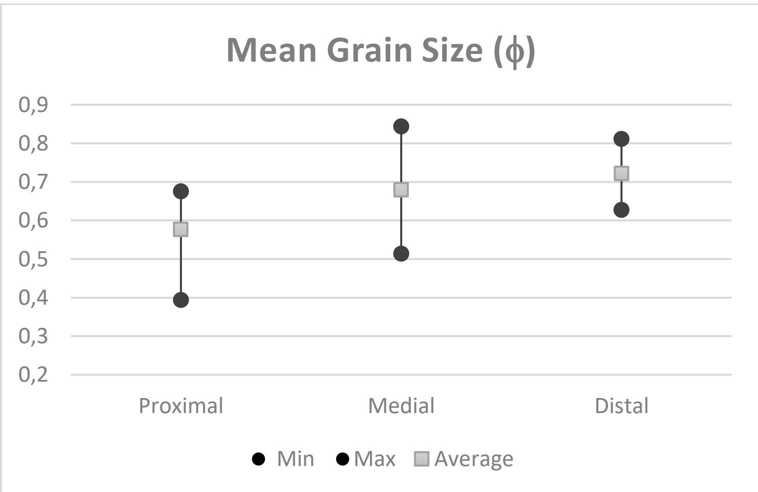

Figure 6. Trend of average grain size across the Opak River channel showing increasing phi unit on distal part which imply relatively higher proportion of finer sediment downstream.

Sorting

Sortation of Opak River channel is indicated by standard deviation of each samples. This approach is conducted to have a precise determination of sediment sortation. Well sorted sediment usually shows lower values of standard deviation. On the contrary, a higher standard deviation value indicates poorly sorted sediment.

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Sediment of Opak River channel shows a maximum value of 1,350 at SP1 and a minimum value of 1,1015 at SD2. Based on Sortation Class of Folks (1974) all sediment samples are categorized as poorly sorted sediment. The standard deviation values do not show significant differences. However, higher values of standard deviation in upstream/proximal part of the river indicates more poorly sorted sediment than the distal part of the river (Figure 7). High energy environment of fast flowing rivers can transport larger and heavier particles resulting in poorly sorted sediment when the energy decreases suddenly and particles are deposited together. The downstream typically characterized by slow moving river caused by a plain topography that typically transport and deposit finer particles, leading to better sorting. It is shown by the decreasing values of standard deviation towards downstream.

The results of mathematical calculation show the maximum values of kurtosis at SD1 with a value of 2,971, and the minimum value is at SM2 with a value of 2,442 (Table 1). Generally, the kurtosis class is mesokurtic except at SM2, which shows a platykurtic class. The kurtosis class of Opak River channel sediment samples shows platykurtic to mesokurtic suggesting that the detrimental sediment has a poor degree of sortation, which is consistent with the sortation value analysis above.

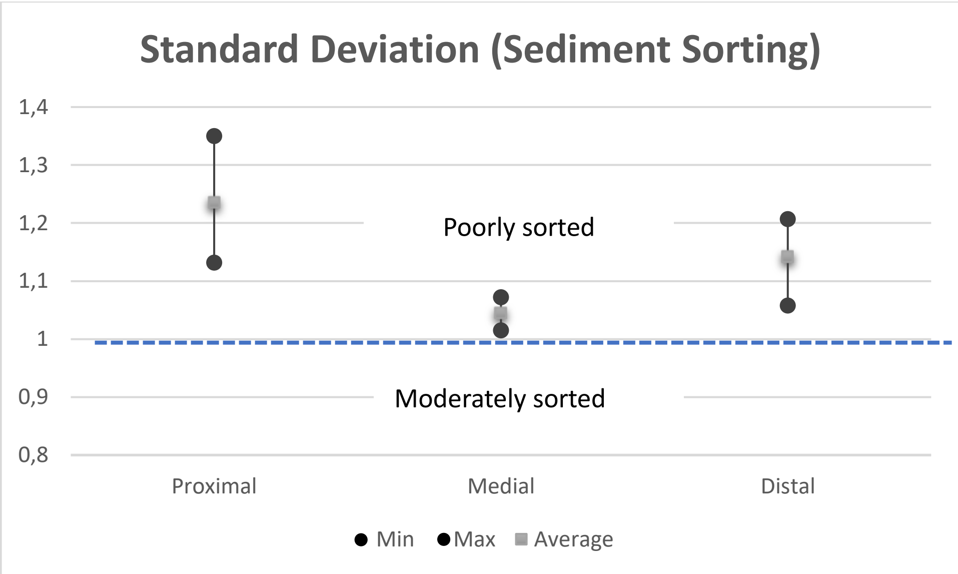

Figure 7. Trend of sediment sorting across the Opak River channel (based on the standard deviation) showing all samples are poorly sorted sediment. The higher standard deviation value implying poorer sorting.

Sphericity and Roundness

The sphericity index of quartz ranges from 0,683 to 0,715 with average value of 0,6962. The values is classified as intermediate to sub-equant (Figure 8). Quartz sphericity values of Opak River channel shows an increasing trend towards the upstream of the river.

The roundedness classes of detrital sediments in the Opak River channel are divided into three relative classes. In the proximal part of the river (SP1, SP2, SP3) shows a relatively angular-subangular class. The medial part (SM1, SM2, SM3, SM4) exhibit a relatively subangular-subrounded class, while the distal part of the river exhibit a relatively subrounded-rounded class (Figure 9).

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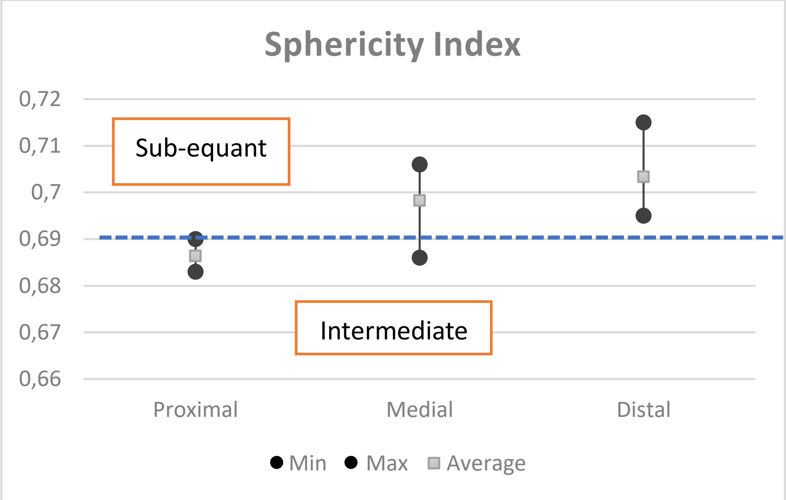

Figure 8. Trend of sphericity index across the Opak River channel showing sediment samples has intermediate to sub-equant. Noted that sediment becomes more spherical/rounded distally indicated by higher sphericity index.

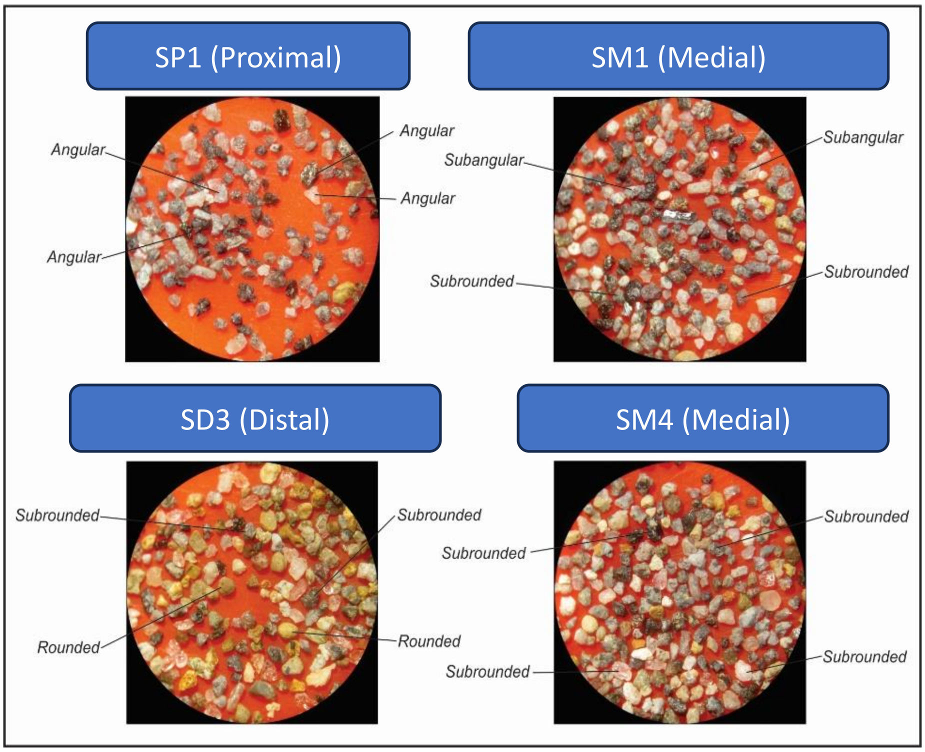

Figure 9. Sand-sized sediments of Opak River channel in various stop site. Noted that sediment becomes more rounded indicated by abundant rounded to sub-rounded minerals in distal sediment samples.

Sedimentary Compositions

The Opak River channel sediment is classified as arkose sediment (Figure 10). Arkose is characterized by its high feldspar content. The proportion of quartz consistently shows increasing trends to the downstream part of the river, while the feldspar content on the contrary shows decreasing trend (Table 6). The proportion of lithic fragment do not show any trend downstream. All samples shows very minor heavy minerals, for instance pyroxene, hematite, amphibole, hematite, ilmenite and and magnetite. Carbonate minerals occur in SM4, SD3, SD2, and SD1. The occurrence of carbonate minerals in Opak River channel sediment may suggest an influx of transported carbonate materials from tributaries (i.e. Oyo River).

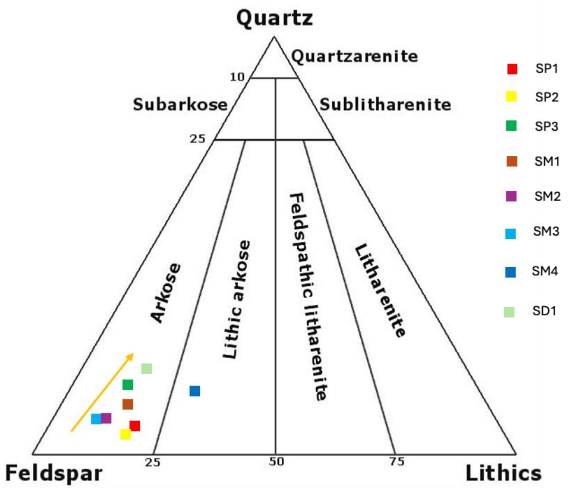

Figure 10. QFL triangle showing all samples sediments plots of quartz, feldspar and lithic fragment. Noted that most samples falls into Arkose type (Feldspar rich), orange arrow indicate increasing quartz content towards distal part of the river.

Table 6. The proportion of quartz, feldspar and lithic of all sediment samples.

No.	Samples	Opak River Zone	Quartz (%)	Feldspar (%)	Lithic (%)	Total (%)
1	SP1	Proximal	4,4	76	19,6	100
2	SP2	Proximal	4	77,5	18,5	100
3	SP3	Proximal	13,8	71,7	14,5	100
4	SM1	Medial	9,9	73,8	16,3	100
5	SM2	Medial	6,3	78,3	15,4	100
6	SM3	Medial	6	80,5	13,5	100
7	SM4	Medial	13,8	60,8	25,4	100
8	SD1	Distal	17,9	66,7	15,4	100

DISCUSSIONS

Sediment Transport Mechanism

The interpretation of sediment transport mechanism is assessed by analyzing the relationship between grain size and depositional processes. Sedimentation mechanism encompasses traction, saltation and suspension populations. These mechanisms are distinguished based on grain size classes on each sediment samples. This study employs the Visher (1969) log probability diagram by plotting grain size classes on a phi scale against the cumulative percentage of each class to ascertain the proportions of sedimentation mechanism populations (Figure 11).

The log-probability diagram results for the Opak River channel samples indicate that sediment transport mechanism is predominantly governed by traction, wherein grain particles transported near the bedform (Table 7). The boundary between the traction and saltation populations (coarse truncation) ranges from 0,75 to 1,25 phi, while the boundary between the saltation and suspension populations (fine truncation) ranges from 2,75 to 3,5 phi. Visher (1969) noted that in modern fluvial samples, coarse truncation lies between -1,5 to 1,0 phi, and fine truncation between 2,75 and 3,5 phi, with the saltation population ranging from 1,75 to 2,5 phi. Hence, the Opak River channel falls into Visher category of typical modern fluvial sample.

The traction mechanism is primarily associated with the coarse sand grain size class or coarser, saltation is predominant in the medium to fine sand grain size class, suspension dominates the very fine sand grain size class or finer. The proportion of traction exhibits a decreasing trend with increasing distance from the upstream of Opak River. This may suggest that the transport distant effectively erodes sediment particles, resulting in finer grains. However, the increase in the traction population at the medial part may indicate an influx of coarse material from surrounding morphography entering the Opak River channel through tributaries, especially Oyo River.

Table 7. Sediment fraction of all samples showing percentage of traction, saltation and suspension.

No.	Samples	Opak River Zone	% Traction	% Saltation	% Suspension	Coarse Truncation	Fine Truncation
1	SP1	Proximal	79	19,1	1,9	1,08	3,35
2	SP2	Proximal	63	31,7	5,3	0,85	3,06
3	SP3	Proximal	64	33,3	2,7	1,13	3,4
4	SM1	Medial	64	33,2	2,8	1	3,07
5	SM2	Medial	60	37,4	2,6	0,93	2,84
6	SM3	Medial	52	44,8	3,2	0,8	3,1
7	SM4	Medial	72	25,6	2,4	1,13	3,28
8	SD1	Distal	59	39,6	1,4	0,8	2,82
9	SD2	Distal	55	42,5	2,5	0,79	2,95
10	SD3	Distal	48	46,5	5,5	0,56	2,86

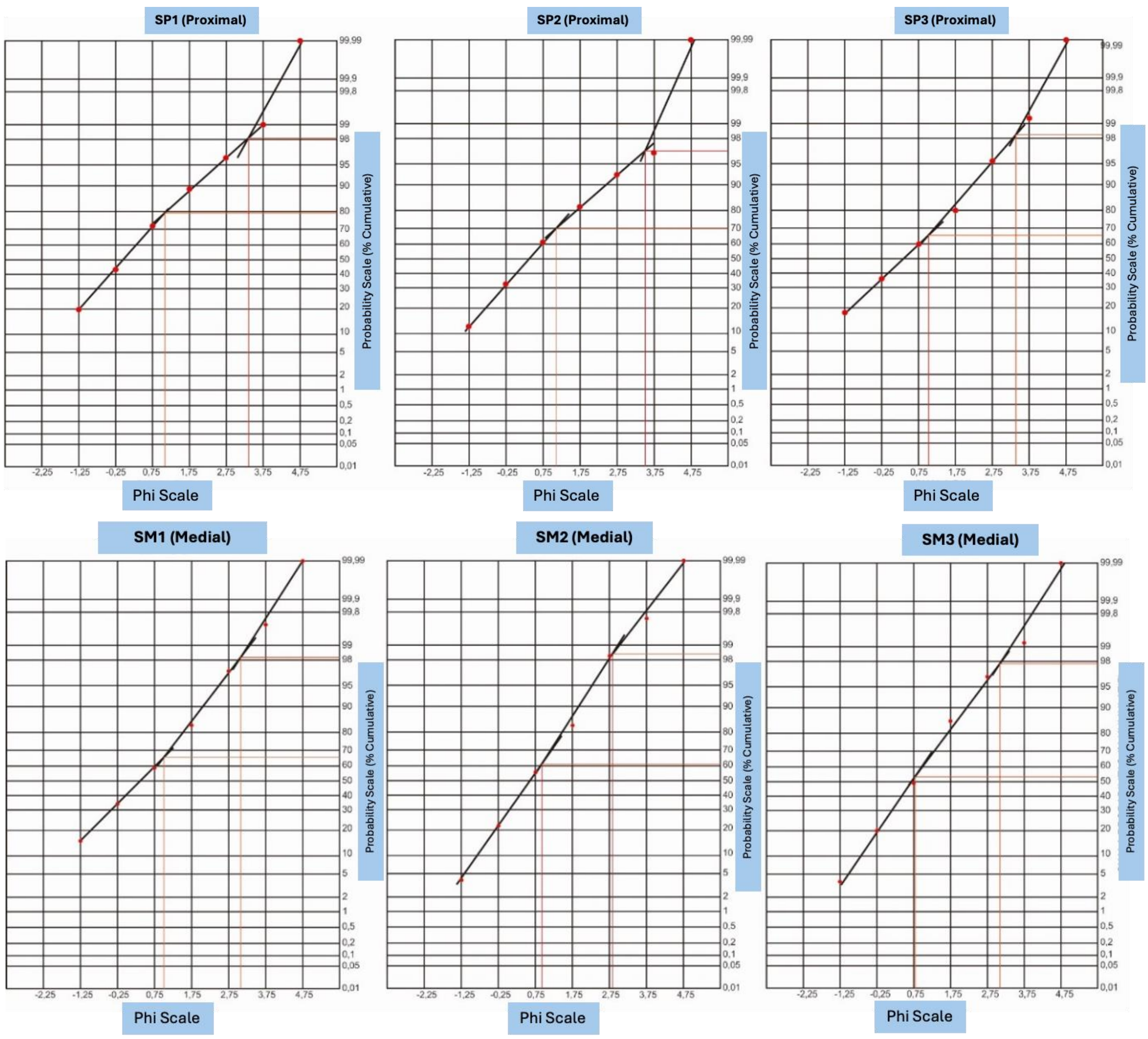

Figure 11. Grain size distribution curve showing each samples cumulative percentage against the grain size.

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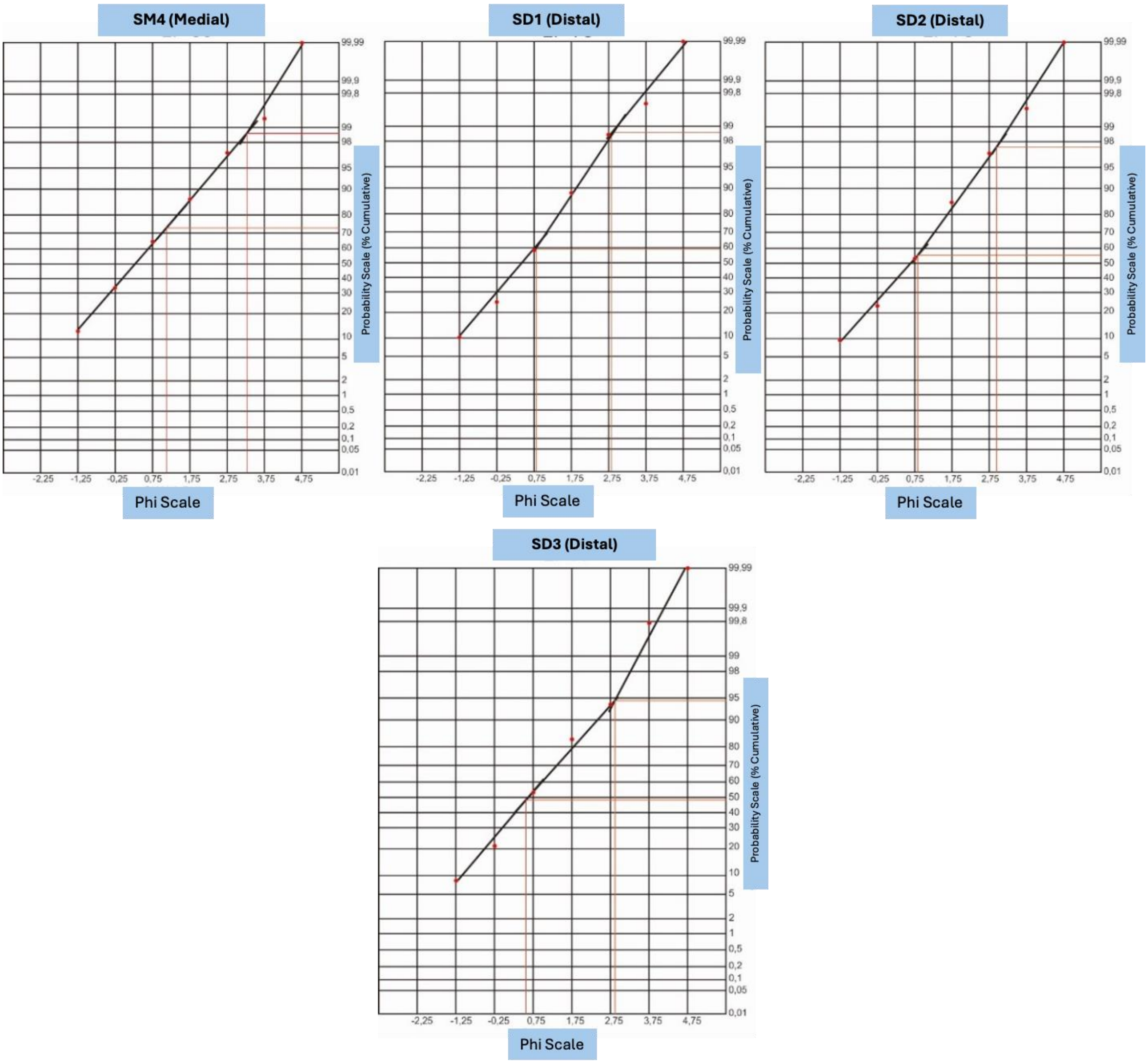

Figure 11. Grain size distribution curve showing each samples cumulative percentage against the grain size. (continued from previous page)

Provenance

The relationship between the composition and their sediment provenance interpreted using the Dickinson and Suczek (1979) QFL triangular diagram (**Figure 12**). The plotting results of quartz, feldspar, and rock fragments from the Opak River channel samples fall within the transitional arc (magmatic arc).

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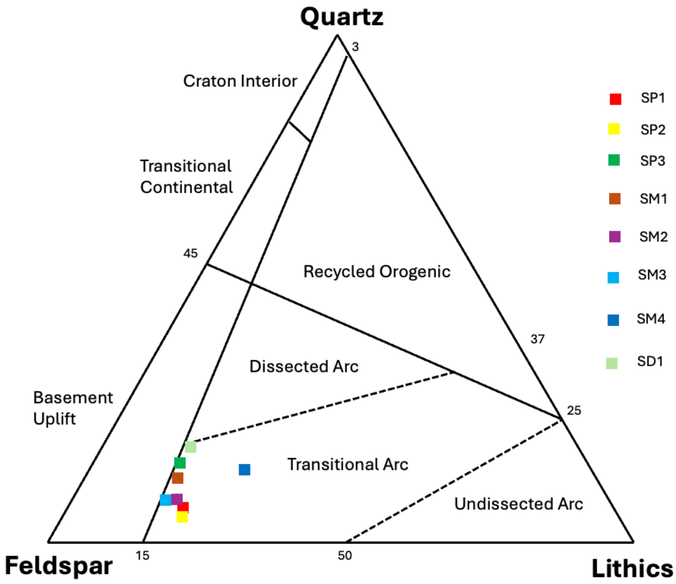

Figure 12. Tectonic setting of sediment provenance. All sediment samples of Opak River channel are suggested to have been derived from magmatic arc-transitional arc settings.

A magmatic arc constitutes a series of positive reliefs composed of plutonic and volcanic rocks may be associated with metamorphic wall rocks formed by ongoing subduction activity (Dickinson, 1985). Consequently, a magmatic arc area is linked to subduction zones, where the primary characteristics of grain in this provenance is volcanoclastic material which may result from eruptions and the erosion of stratovolcano-type volcanic chains (Dickinson, 1985). The Opak River channel samples classified within the transactional arc exhibit a feldspatholithic petrofacies shown by a significant presence of feldspar followed by rock fragments. This characteristic aligns with the primary compositional attributes of the magmatic arch provenance type.

Opak River receives transported sediment from tributaries that may be derived from eroded older rocks from Southern Mountain Zone. The occurrence of heavy minerals such as pyroxene, amphibole, ilmenite could be derived from volcanic rocks (quaternary or older volcanic clastic, e.g.. Semilir Formation, Nglanggran Formation). This align with the provenance analysis that suggest magmatic arc source. Carbonates grains were also found in the medial part of the Opak River. Carbonate grains hardly precipitate in fluvial systems. Thus, the occurrence of carbonate grains suggests an input from carbonate source, for instance Oyo and Wonosari Formation in Oyo River.

CONCLUSIONS

The statistical characteristics of the Opak River Channel sediment revealed that the mean value exhibit a coarse grained sediment with poor sortation. The skewness analysis of the sediment samples shows all positive skewness with vary. Detailed analysis on the skewness values shows a decreasing trend as the distance from the river upstream increases. The kurtosis class of Opak River channel sediment samples shows platykurtic to mesokurtic suggesting that the detrimental sediment has a poor degree of sortation. Based on sphericity and roundness, the sediments are intermediate to sub equant and angular to subrounded, respectively. It is concluded that the traction predominates Opak River channel transport, while the saltation and suspension mode is consistently minor mode of sediment transport indicated by relatively lower percentage of saltation/suspension fraction. Sediment of Opak River channel is characterized by high percentage of feldspar. QFL analysis suggested that sediment originated tectonically derived from a magmatic arc setting, specifically a transitional arc subtype. The primary sediment source could have been derived from quaternary volcanic rock (Mount Merapi) or older volcanic rock (Semilir Formation and/or Nglanggran Formation) with a potentially strong influence of the Oyo River, especially in the medial to distal part of Opak River indicated by the occurrence of carbonate grains.

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