THE EFFECTS OF BASIN GEOLOGY ON THE GRAIN SIZE CHARACTERISTICS OF BED MATERIALS AND THE VARIABILITY OF BEDFORM CONFIGURATION AMONG ALLUVIAL RIVERS

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ABSTRACT

This study observed and characterized the bed materials of 20 alluvial fan rivers across central Japan and the Hokkaido island. These rivers were classified among the 3 typical basin geologies of Japan: granite rock basin, volcanic rock basin, and accretionary complexes basin. According to the measurements, it was found that the amount of aggregates larger than 2mm, correlates with the weathering characteristics of different rocks. Due to lesser boulder and cobble fractions, the bed materials in accretionary complexes rivers are finer than granite rock rivers and volcanic rock rivers. However, the fractional sand contents of alluvial fan rivers are mainly influenced by the total sediment yield from upstream. Only if the sediment yield is sufficiently high, sand can deposit on the bed surface. Moreover, the measurement showed that in alluvial fan rivers, high sand content generates the bimodal distribution of bed material. Therefore, this study proposed a simple method that can quantitatively estimate the characteristics of Grain Size Distribution (GSD), by utilizing sand content and standard deviation σ_G of gravel aggregates (>2mm). Finally, it was clarified the magnitude of bedform variability in accretionary complexes basin >> granite rock basin (high sand content rate) > volcanic rock basin. It suggests that the characteristics of GSD greatly influences the bedform variability, which is attributed to weathering characteristics of basin geology.

Keywords: Alluvial fan rivers, Grain size distribution, bedform configuration, Riverbed materials

1. INTRODUCTION

The bed materials of alluvial rivers were observed to have varying characteristics of grain size distributions (GSD). Nevertheless, lognormal distribution and bimodal distribution remain the typical grain size distributions in alluvial rivers (Sulaiman et al., 2007). On the other hand, the generic approach to assess the influence of geology condition in the upstream area on the properties of bed materials have been studied for many years. Wolcott (1988) reported that the river in sandstone and siltstone basin has the bimodal GSD, whereas basalt basin has the unimodal GSD, due to the different weathering properties among these rocks. Recently, Attal and Lavé (2006, 2009) conducted field measurements and experiments to clarify the effects of abrasion resistance on grain size distribution by comparing quartzite, gneiss, and schist. Furthermore, Koide (1973) and Chibana (2014) have done more extensive studies on characterizing the weathering properties among different rocks throughout Japan island. They reported that there are distinguish weathering properties among granite rock, volcanic rock, and sedimentary rock. Granite rocks were observed to weather into sand or large boulder (>1024mm); therefore, it can supply a large amount of sand and boulder to rivers. Volcanic rocks mainly produce cobble and boulder, coupled with the low sand production rate, with an exemption to quaternary volcanos, which may produce more sand due to the weathering of the constituents (Lava, volcanic dust, etc.). Sedimentary rocks generate the least coarser materials, especially the boulders. However, these previous studies were conducted qualitatively. Therefore, to verify and quantify these results, field surveys and measurements must be done to estimate and evaluate the relationship between lithology and bed material GSD.

The effects of GSD on the bedform characteristics have been investigated and discussed experimentally (Ashida et al., 1991), and numerically (Lanzoni and Tubino 1999), yet, remain poorly understood. Due to the lack of field surveys, the situation on the field is still unclear (William et al., 2016).

This study aims to clarify the influence of different geological conditions of upstream basins on the characteristics of alluvial fan riverbed material's GSD; and detect the variation of bedform configurations due to the characteristics of GSD.

2. STUDY RIVERS AND METHODOLOGY

2.1 Observation of riverbed materials

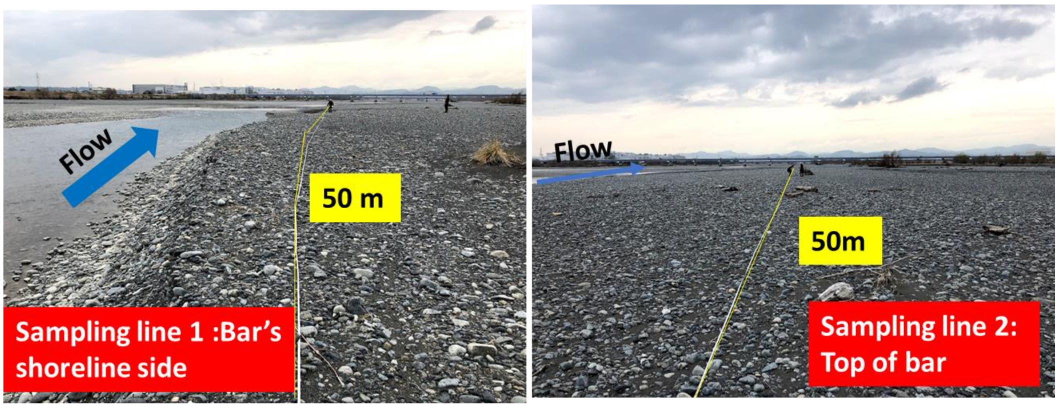

Figure1. Method of line sampling in the field (Sampling grains in every 1m, along the sampling line, 51 grains in each line, 102 grains in total for each site.)

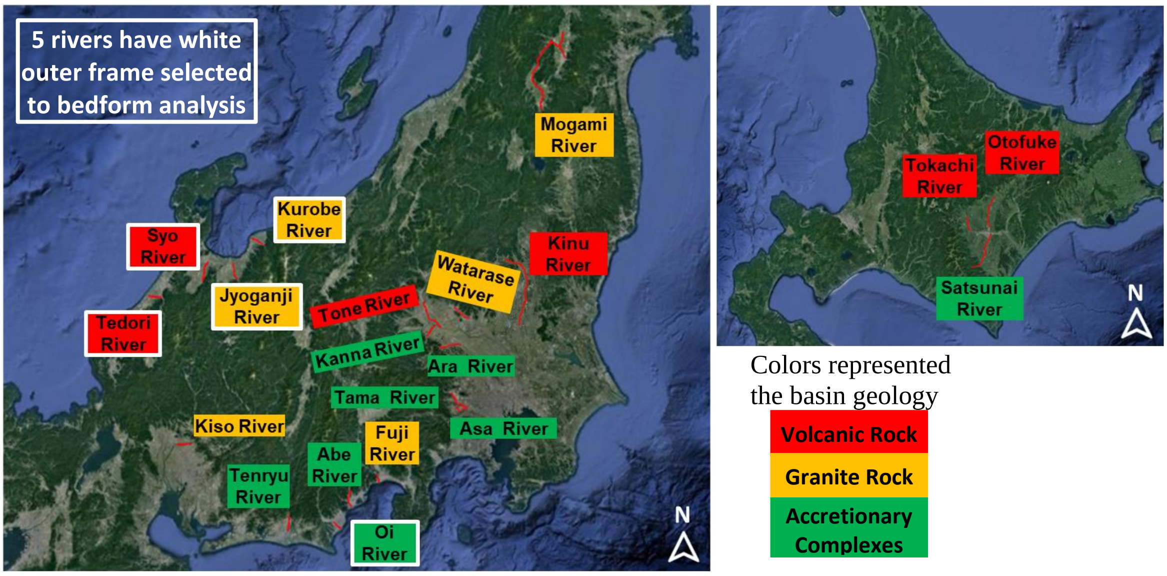

Figure2. Twenty (20) study alluvial rivers

Figure 1 shows the locations of the twenty (20) study rivers across central Japan and Hokkaido region representing the various geological condition of basins. The basins were classified based on their primary geology type, which represents the largest area ratio within the basin. Study rivers were clustered into 3 groups: volcanic rock basins, granite rock basins, and accretionary complexes basins (belongs to the sedimentary rocks classified by Koide (1973) and Chibana (2014)). The sites for bed material measurement were located at the channel sections near the alluvial fan's apex, middle, and toe, to ensure that the properties of bed material along the whole alluvial fan channel were represented. A single GSD curve was generated by combining the data from all sites in each river. A total of 76 sites measurements were conducted by line sampling (shown in Figure 2) along study rivers.

2.2 Estimation of bedform configuration

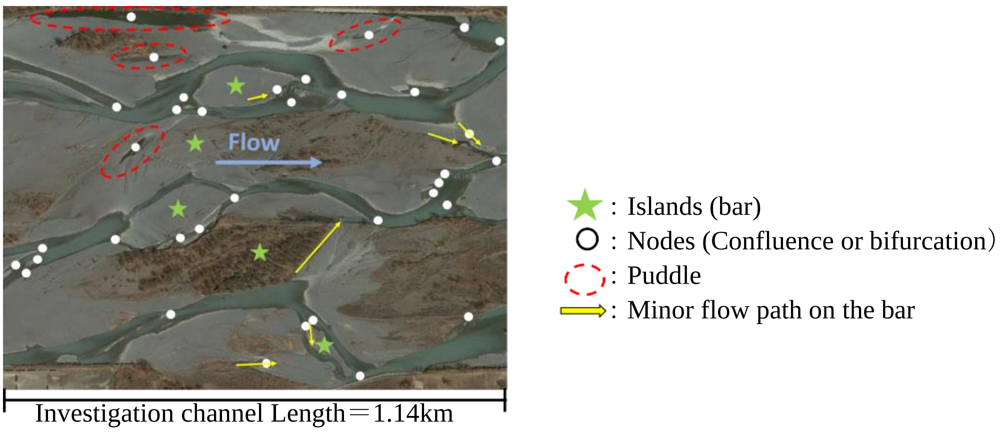

Figure 3. Sample section for braiding intensity calculation

Five (5) alluvial fan rivers (with white outline, as shown in Figure 2), representing the 3 typical basin geologies of Japan, were selected to estimate the annual variability of bedform configuration. Three (3) indexes of braiding intensity (Eq. (1) - (3)): Bar numbers of braiding intensity (N_b); Node numbers of braiding intensity (N_n); Node density of bars(D_n); were calculated using aerial photographs to estimate the bedform configuration quantitatively (Figure 3). Historical aerial photographs of 5 rivers were selected every 10 years from the 1940s to the late 2010s, to investigate the annual variation of bedform configuration.

$$N_b = \frac{The\ number\ of\ Bars\ (Island)}{Length\ of\ investigation\ channel} \tag{1}$$

$$N_n = \frac{The\ number\ of\ nodes}{Length\ of\ ivestigation\ channel} \tag{2}$$

$$D_n = \frac{N_n}{N_b} \tag{3}$$

Where,

N_b = Bar numbers of braiding intensity, N_n = Node numbers of braiding intensity, D_n = Node density of bars.

3. CHARACTERISTICS OF BED MATERIALS AMONG DIFFERENT BASIN GEOLOGICAL TYPES

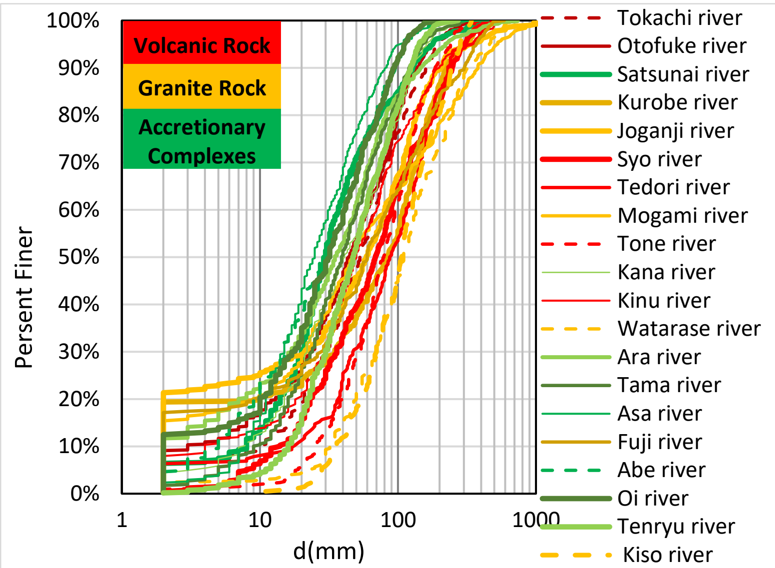

Figure 4. Grain-size distribution curves of 20 alluvial fan rivers

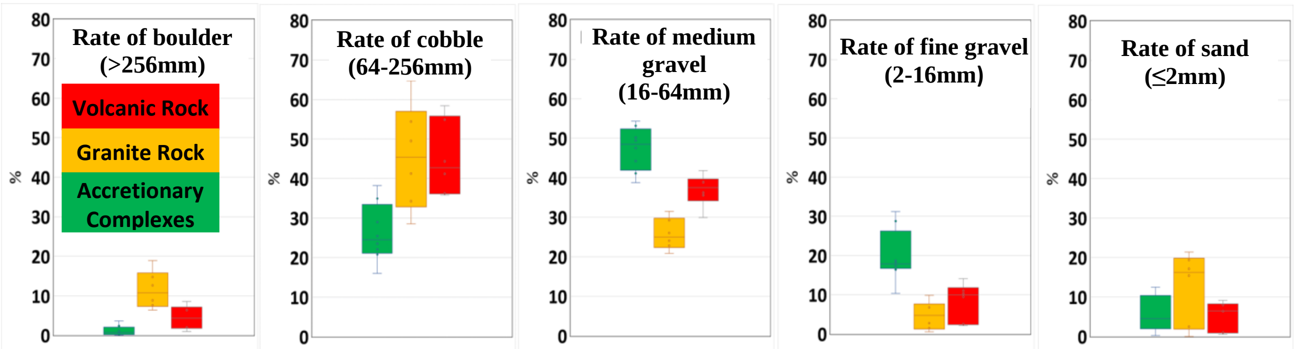

Figure 5. The variation of aggregates' grain-size fractional content among the 3 different basin geologies

Figure 4 shows the GSD curves of 20 alluvial fan rivers, color-coded per basin geology. It shows that regardless of bed slope among target rivers, the size of bed materials of granite rock basins is larger than volcanic rock basins', followed by accretionary complexes basins. Moreover, by comparing the fractional content of aggregates' grain-size in bed material, as shown in Figure 5, it was found that the content rate of each grain-size fraction showed different characteristics among these 3 basin geology types. The granite rock basins and volcanic rock basins contained significantly more boulders (>256mm) and cobbles (64-256mm) than accretionary complexes basins. Notably, the amount of boulders showed a clear difference among these 3 basin geologies, with the relative amount in the following order: granite rock basins > volcanic rock basins >>

accretionary complexes basins. Furthermore, granite rock basins and volcanic rock basins both have cobbles as the main aggregate fraction of its bed material. On the other hand, accretionary complexes basins contained the least boulder and cobble fraction, while having the most medium gravel (16-64mm) and fine gravel (2-16mm). These characteristics coincide with the weathering characteristics of different rocks reported by Koide (1973) and Chibana (2014). The finest sand aggregates (≤2mm; assumed regardless of the weathering characteristics of rock types), exist sparingly on the bed surface, due to the steepness of alluvial fan. However, it was observed that the granite rock basins showed a distinct characteristic that could further classify the rivers into 2 groups: (1) lowest sand content rate near to 0%, (2) highest content rate, near to 20%. As shown in Figure 4, Mogami river, Kurobe river, Jyoganji river, and Fuji river have the highest sand content rate among granite rock basins. These rivers are all reported to have massive denuded lands in their upstream due to landslides and slope failure. In contrast, Watarase river and Kiso river, which both belong to the lowest sand content rate group, do not have such severe sediment disasters as former rivers. Similarly, in volcanic rock basins and accretionary complexes basins, rivers have massive denuded lands in the upstream, also tended to show a higher sand content rate, around 10%, such as Kinu river, Tedori river, Oi river, and Abe river. This result indicates that the sand content rate in alluvial fan rivers may be enhanced by the high sand yield resulting from the weathering characteristics of granite rock. More importantly, the total sediment yields from basins must be sufficiently high.

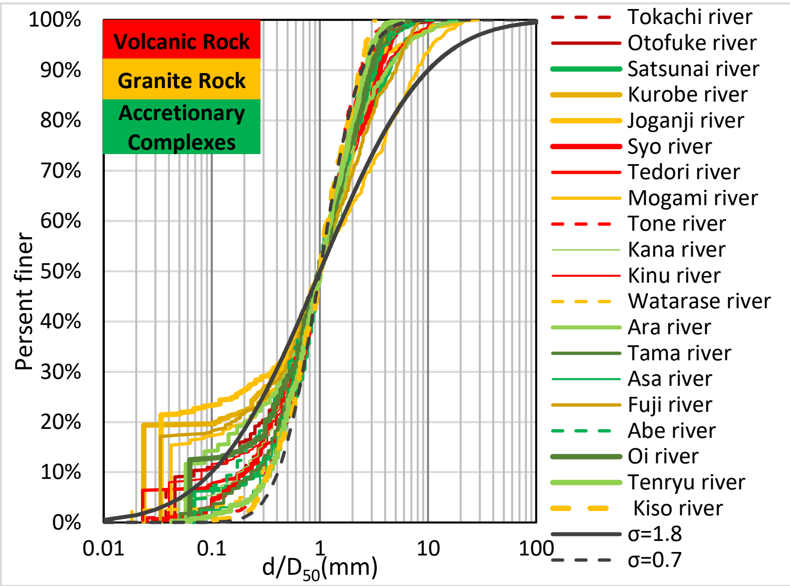

Figure 6. Dimensionless GSD curves (standardized by D_{50}) of all bed materials in 20 alluvial fan rivers (Rivers have high sand content rate, cannot be estimated by σ precisely)

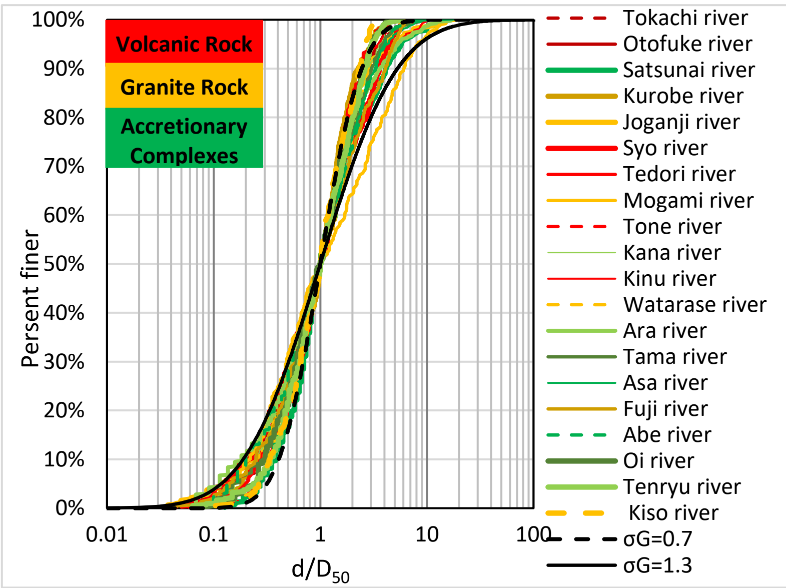

Figure 7. Dimensionless GSD curves (standardized by D_{50}) of gravel aggregate (>2mm) in 20 alluvial fan rivers

Subsequently, according to the measurements, it was found that the bimodal distribution of bed material in alluvial fan rivers were generated by the high sand content rate (Figure 4, Figure 6). It means that, if the sand aggregate content was ignored, the rest aggregates (>2mm) represent a lognormal distribution. In this study, gravel aggregates are referred to as aggregates larger than 2 mm. Therefore, it is proposed to use the sand content rate and the standard deviation σ_G of gravel aggregate's dimensionless GSD (was calculated by Eq. (4)) to estimate the variance of the GSDs quantitatively.

$$p(ln\ (d)) = \frac{1}{\sqrt{2\pi}\sigma_G} exp\left[-\frac{(ln\ (d) - ln\ (D_{50}))^2}{2{\sigma_G}^2}\right] \quad (4)$$

where,

p(ln(d)): probability density, d: grain size, D_{50}: the diameter corresponding to 50% finer in the GSD curve, σ_G: standard deviation of gravel aggregate's(> 2mm) size distribution.

The gravel aggregate's dimensionless GSD curves were reproduced by dividing the grain's diameter by D_{50}, as shown in Figure 7. Figure 7 shows that all the GSD curves fell in the range of $0.7<\sigma_G<1.3$, and there was no significant difference among 3 basin geologies. Thus, these results suggest that the basin geology mainly influence the grain-size aggregate content rate in bed material. However, the formation of characteristics of GSD should be considered from the influence of flow conditions in each river as well.

4. VARIABILITY OF BEDFORM UNDER DIFFERENT TYPES OF BASIN GEOLOGY

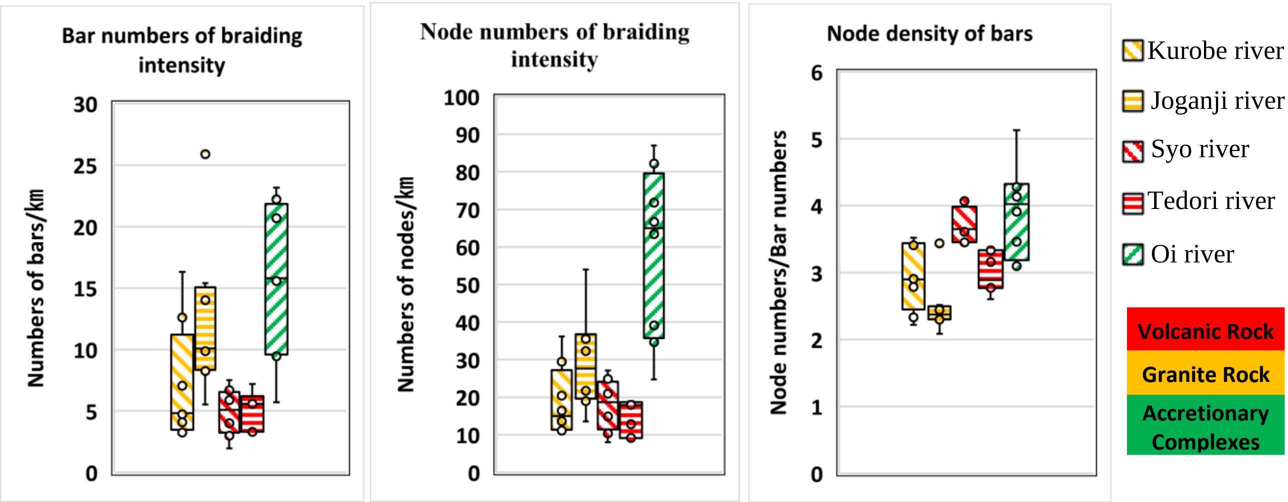

Figure 8. The variation of bedform

To minimize the impact of river development/regulation on the results of this study, 5 alluvial fan rivers which flow from the Japan Alps were selected: Kurobe river, Jyoganji river, Syo river, Tedori river, and Oi river (shown in Figure 2). These rivers were assumed to have limited bed degradation compared to other highly regulated rivers in Japan. Figure 8 shows that the 3 indexes of braiding intensity used to estimate the bedform, all show the same trend of variability corresponding to their basin geology. The relative magnitude of bedform variability among 3 basin geologies was observed in the following order: accretionary complexes basin >> granite rock basin > volcanic rock basin. This result may be explained by the characteristics of the GSD in each basin geology, which was clarified before. Since accretionary complexes basins contain few boulder and cobble aggregate, with medium gravel as its main aggregate, the bed material tends to be finer than granite rock basins and volcanic rock basins. It also indicates that the bed material in accretionary complexes basins can be transported actively during the shorter return period floods, compared to granite rock basins and volcanic rock basins. Therefore, the bedform variability was found to be highest. On the other hand, the study rivers which belong to the granite rock basins, such as Kurobe river and Jyoganji river, both contained around 20% sand in bed material. In contrast, the sand fraction of the volcanic rock basin, Syo river and Tedori river were less than 10% (Figure 4). According to the experiment conducted by Ikeda and Iseya (1987), increasing sand content enhances the mobility of gravels. Based on this result, it may be inferred that the difference of bedform variability between granite rock basins and volcanic rock basins is attributed to the significant difference of sand content. In other words, the coarse aggregates of the rivers in granite rock basins, which have higher sand content, can easily be entrained by flow, so the bedform variation becomes high. Conversely, the volcanic rock rivers, which are characterized by its lack of sand content, have stable coarse aggregates, effectively restraining bedform variation.

5. CONCLUSIONS

This study observed the riverbed materials of 20 alluvial fan rivers representing the 3 major basin geology of Japan: granite rock basin, volcanic rock basin, and accretionary complexes basin. According to the measurements, it was found that the content rate of the gravel aggregate (>2mm), is strongly influenced by the weathering properties of different rocks. The main material in granite rock rivers and volcanic rock rivers are cobble. These rivers also contain significantly higher amounts of boulder and cobble than accretionary complexes rivers, which are mainly composed of medium gravels. However, it was clarified that the content rate of sand aggregate in alluvial fan rivers is more dependent on the total sediment yield from upstream. The basins which have massive denuded lands tend to have sand content higher than 10%. Moreover, the measurement showed that this high sand content rate generates the bimodal distribution of bed material in alluvial fan rivers. Accordingly, the study suggested a simple method that can quantitatively estimate the GSD properties by utilizing sand content rate and the standard deviation σ_G of gravel fraction (>2mm). The study also demonstrated that the bedform variability is greatly influenced by the characteristics of GSD, which is attributed to weathering characteristics of basin geology. It was confirmed that the magnitude of bedform variability among these 3 basin geologies is accretionary complexes basin >> granite rock basin (high sand content rate) > volcanic rock basin.

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