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# Suspended sediment transport in two headwater basins with different bedrock: A case study in the Ashio Mountains, Japan

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**Abstract**

Suspended sediment transport in storm events was observed in two headwater basins (C3 and S3) with different bedrock. C3 basin is underlain by bedded chert, whereas S3 basin is underlain by alternation of sandstone and shale. Concentrations of suspended sediment in S3 basin were significantly higher than those in C3 basin for storm events with similar water discharge magnitude. The difference in grain size of colluvial sediment, which is a source of suspended sediment, must cause the contrasting sediment transport regimes in the two basins. For S3 basin, the amount of sediment transport including suspended and bed load was at least 5 times larger than the coarse fraction (> 2 mm) of the deposited sediment in a bed load trap for an observation term in 2009.

**Key words:** headwater stream, Mesozoic sedimentary rock, sediment transport, suspended sediment

## 1. Introduction

Suspended sediment transport is one of the essential geomorphic processes in headwater streams. Many researchers observed concentration of suspended sediment (SS) in headwater streams to investigate the effects of subsurface flow on SS transport (Terajima et al., 1997), effect of logging on SS transport (Lewis et al., 2001), or SS transport regime in debris-flow-prone channels (Nistor and Church, 2005). Few studies, however, focused on the effect of bedrock types on SS transport in headwater streams. Although Hirose et al. (1995) observed SS transport in the four headwater basins with different bedrock types (granite, granodiorite, gabbro and limestone) in the Abukuma Mountains, they did not find clear differences in SS transport regimes between the four basins.

The aim of the present study is to reveal the SS transport regimes in two small headwater basins with different bedrock types (C3 and S3 basins in Fig. 1). The previous hydrogeomorphic observations in these basins revealed that runoff process, bed sediment transport and channel morphology are clearly contrasting (Hattanji and Onda, 2004; Wasklewicz and Hattanji, 2009; Hattanji et al., 2012). Therefore, observation of SS transport in these basins is significant for testing the effect of underlying bedrock on SS transport.

## 2. Study sites

The two headwater basins are located in the eastern part of Ashio Mountains, Tochigi Prefecture, Japan. Annual precipitation ranges from 1400 to 1600 mm and mean annual air temperature is ~13°C. These two basins are used for forest plantation of Japanese cedar and Japanese cypress.

Geomorphic features of the two basins are contrasting. Bedrock is partly exposed on steep slopes in C3 basin underlain by bedded chert where colluvial sediment composed of gravel (~ 80% in weight) accumulates below the steep bedrock exposures. Slopes in S3 basin underlain by alternation of sandstone and shale are mostly covered with regolith or colluvial sediment, in which more clay and silt are contained (~40% in weight, Hattanji and Onda, 2004).

## 3. Methods

Flume and box-type bed-load traps were installed at the outlet of C3 and S3 basins (Fig. 1B). Stream water discharge at these flumes was measured with capacitive water-level sensors. Details on the methods for these fundamental observations were described in the previous papers (Hattanji and Onda, 2004; Hattanji et al., 2012).

An automatic water sampler (ISCO 3700C) was installed at the outlet of S3 basin from 2008 to 2009. The water sampler was moved to the outlet of C3 basin in 2010. For both sites, a water inlet of the water sampler was fixed in a bed-load trap filled with stream water. During the first observation year (2008), the sampler was automatically activated when the water level in the flume exceeded a critical value. For the second and third observation years (2009 – 2010), the sampler was manually activated before a storm event based on weather forecast. For both cases, the sampler collected stream water with a volume of 410±20 mL at 1 h interval. The collected water samples were filtered by suction using a filter with a pore size of 0.45 μm. The dry weight of SS on the filter was measured after oven drying at 100°C for 24 h. Loss on ignition (*LOI*) of the collected samples were measured to

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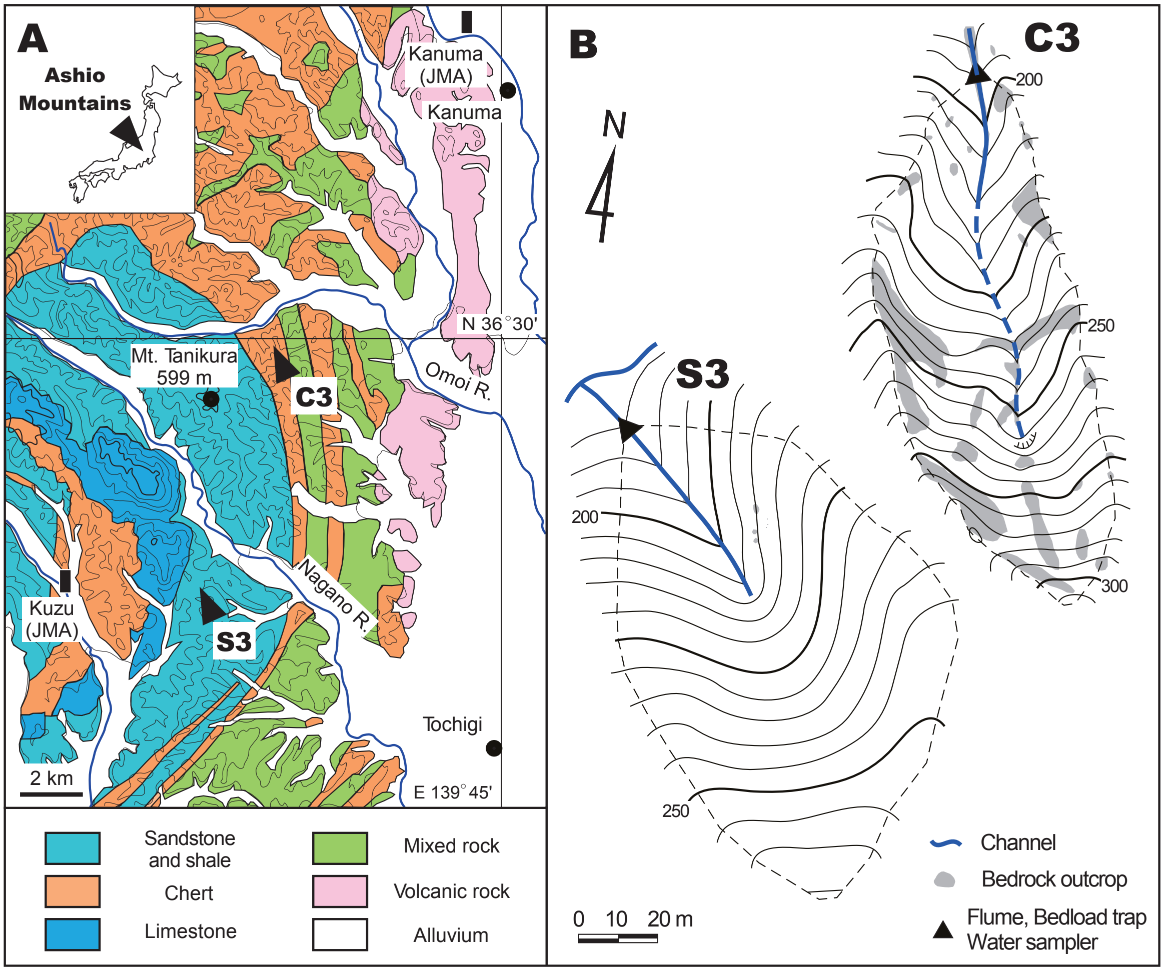


Fig. 1. Study area and two headwater basins in the Ashio Mountains, Tochigi Prefecture, Japan. A. geological map of the study area. B. topographic map of C3 and S3 basins. Geological map is modified from Sudo et al. (1991). The contour interval of Fig. 1B is 5 m. The blue broken line in Fig. 1B shows ephemeral channel.

separate mineral and organic components in SS. The samples were heated at 750°C for 1 h in a muffle furnace, and this treatment was repeated four times before weighing. Total amount of SS transport (*SST*) for each event was calculated from the following equation (1),

$$SST = (1 - LOI)\sum_{i=1}^{n} s_i Q_i \qquad \cdots (1)$$

where $n$ is the number of collected samples for the observed event, $s_i$ is concentration of SS in the $i$-th sample including both mineral and organic components and $Q_i$ is mean stream discharge at the collection of the $i$-th sample.

## 4. Results

Two samples were automatically collected at S3 basin during a thunderstorm event on 16 August, 2008 (Event A, Fig. 2). The total amount of rainfall was 81.5 mm and peak intensity was 55.5 mm/h at Kuzu (JMA AMeDAS station, Fig. 1A). The first and second samples were collected at a rising stage of storm hydrograph (1.5 L/s) and at a peak (4.9 L/s), respectively. The concentration of suspended sediment (SS) was 12.9 g/L for the first sample, and 11.7 g/L for the second sample. Loss on ignition (*LOI*) was 0.281 (28.1%) for the first sample and 0.161 (16.1%) for the second sample. Total amount of SS transport for Event A was not calculated due to the limited number of samples.

Total 86 samples were collected at S3 basin from 7 October to 28 November, 2009, in which two major and two minor events were observed. For Event B (7–8 Oct., 2009), total rainfall was 58 mm and peak intensity was 10.5 mm/h at Kuzu. Peak discharge was about 0.54 L/s (Fig. 2). For Event C, total rainfall was 49 mm and peak intensity was 9 mm/h, although some samples at runoff peak were lacked due to system trouble. Total rainfall for

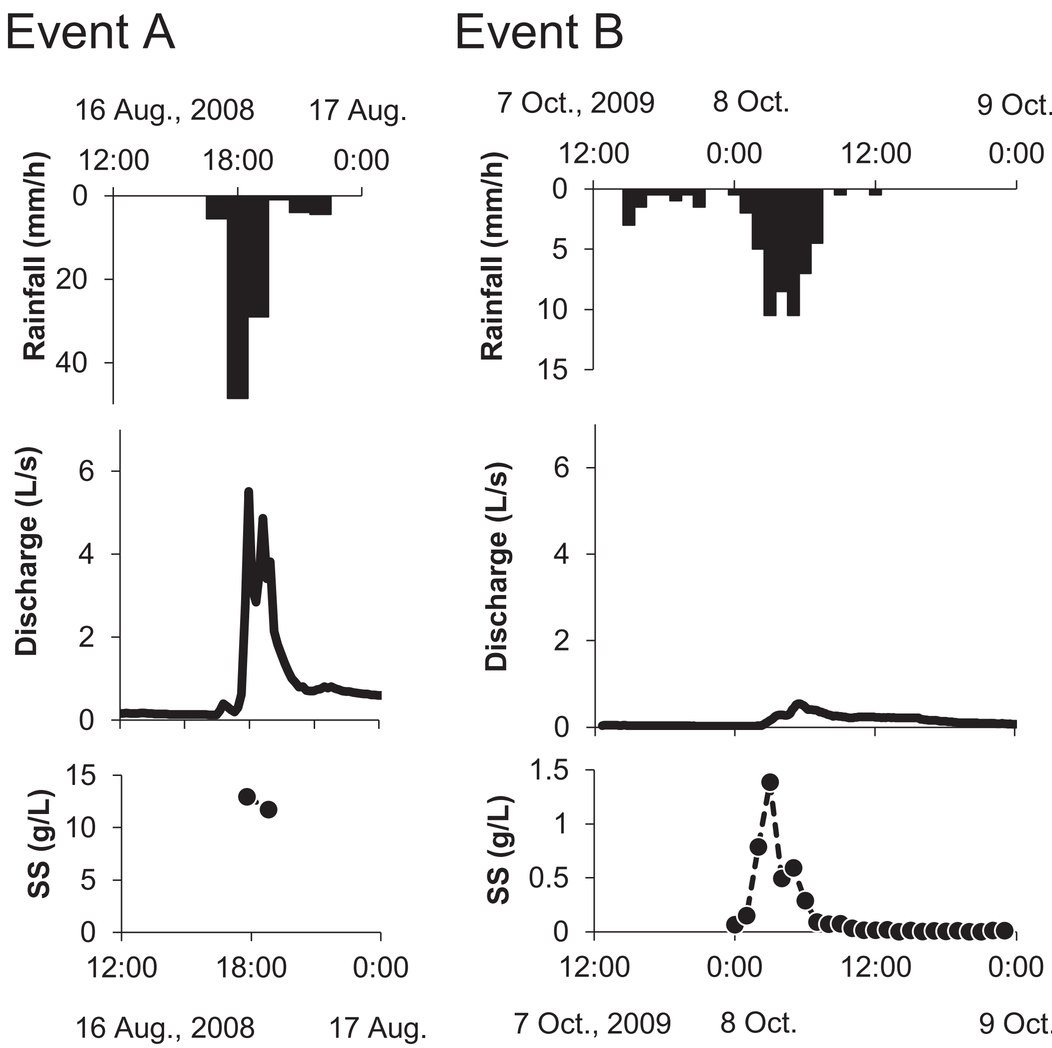


Fig. 2. Hydrograph and temporal change in concentrations of suspended sediment (SS) for Event A (16 Aug., 2008) and Event B (7–8 Oct., 2009) in S3 basin. Hourly rainfall was referred to the data of JMA AMeDAS 'Kuzu'. Note that the scales for rainfall and SS concentration are different between the Events A and B.

the other two minor events was less than 20 mm each, and the peak discharge was less than 0.12 L/s. Concentration of SS for these events ranged from 0 to 1.4 g/L (Fig. 2). The values of LOI were 0.368 (36.8%) for all samples of Event B and 0.402 (40.2%) for all samples of Event C and the other two events. The SS samples of these events contained more organic materials than those of Event A. Total amount of SS transport was 1.9 kg for Event B and 0.5 kg for Event C and the two minor events, although the latter must be underestimated due to the data lack in Event C.

Total 46 stream water samples were collected in C3 basin for two major events (D and E) from April to May in 2010. For Event D (12–13 Apr., 2010), total rainfall was 45 mm and peak intensity was 6.5 mm/h at Kanuma (JMA AMeDAS station, Fig. 1A). For Event E (23–24 May, 2010), total rainfall was 88.5 mm and peak intensity was 6 mm/h at Kanuma. Peak discharges were 2.1 L/s for Event D and 6.7 L/s for Event E (Fig. 3). These peak discharges, however, were smaller than a critical discharge for significant bed load transport in C3 basin (Hattanji and Onda, 2004; Hattanji et al., 2006). Concentration of SS ranged from 0 to 0.03 g/L. LOI for these events was not able to be measured due to the lack of the total amount of SS samples. The total amounts of SS transport were about 0.2 kg for Event D and 1.0 kg for Event E, in which organic materials were included (i.e. *LOI* = 0).

## 5. Discussion and conclusions

Fig. 4 shows SS concentrations plotted against stream

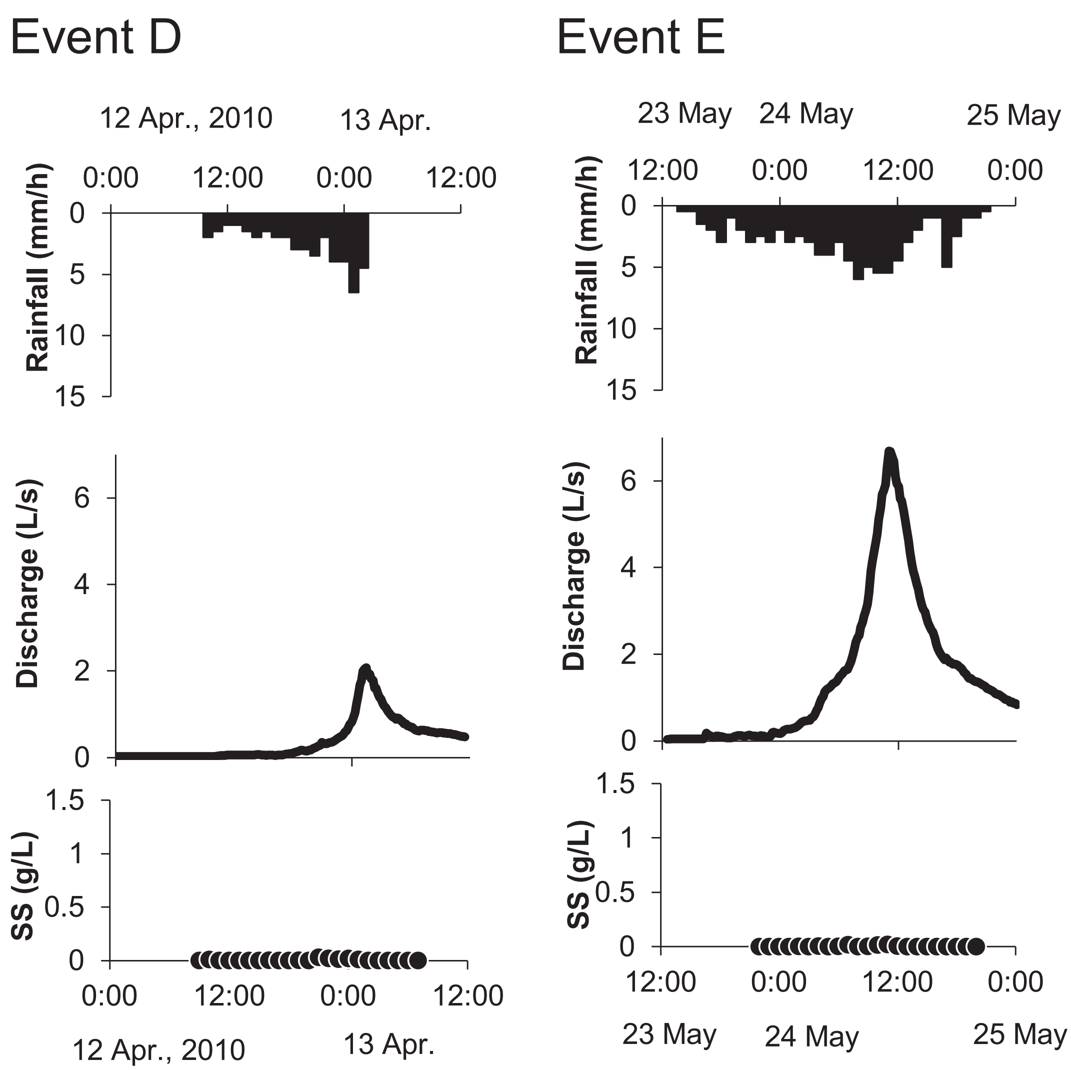


Fig. 3. Hydrograph and temporal change in concentrations of suspended sediment (SS) for Event D (12 – 13 Apr., 2010) and Event E (23–24 May 2010) in C3 basin. Hourly rainfall was referred to the data of JMA AMeDAS 'Kanuma'.

water discharge for all the observed storm events. S3 basin had significantly higher SS concentrations than C3 basin for discharge of 0.1 – 10 L/s. The cause of the contrasting pattern between C3 and S3 basins must be the difference in grain size of colluvial sediment on slope, i.e., the source of SS. As reported in the previous papers (Hattanji and Onda, 2004; Hattanji et al., 2012), content of fine particles (sand, silt and clay) is ~70% in weight for S3 basin, while it is <20% for C3 basin. The availability of fine particles for SS transport is extremely restricted in C3 basin where physical weathering predominates.

The contrast in availability of fine particles between C3 and S3 basins in the Ashio Mountains is more obvious than the four basins in the Abukuma Mountains (Hirose et al., 1995). Although runoff processes are clearly different in the four basins of Abukuma (Hirose et al., 1994), colluvial material in these basins is mainly composed of fine particles; >90% for granite, gabbro and limestone, and ~80% for granodiorite (Terada et al., 1994). The difference in grain size would be a major cause for contrasting results between the present study and Hirose et al. (1995).

The total amount of SS transport was precisely calculated for an observation term of bed load transport (7 October to 28 November, 2009) in S3 basin. In this term, coarse sediment (grain size of > 2 mm) of 0.54 kg was deposited in the bed load trap of S3 basin. As described in the result section, the total amount of SS transport for all the storm events in this term (Events B and C and two minor events) was more than 2.4 kg. These facts indicate that total sediment transport was more than 2.94 kg,

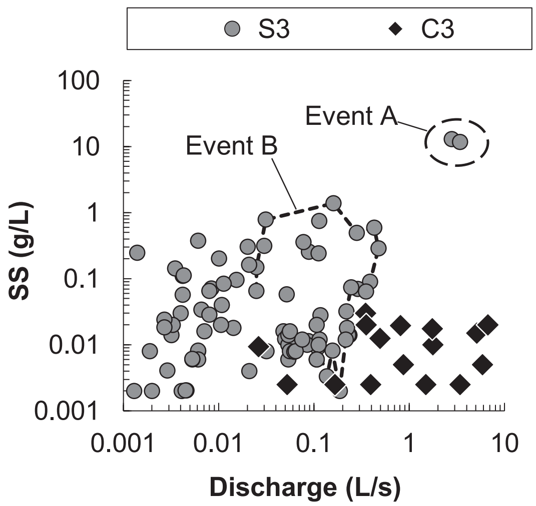


Fig. 4. Concentrations of suspended sediment (SS) plotted against stream discharge for all the storm events in C3 and S3 basins.

which was at least 5 times larger than the amount of the coarse sediment deposited in the bed load trap. This fact is essential for estimating annual or decadal sediment transport in S3 basin based on a record of bed load transport for more than 6 years.

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