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DEBRIS-FLOW BEHAIVIORS IN A STEEP MOUNTAINOUS TORRENT ON OHYA LANDSLIDE, JAPAN

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Debris flow is one of the most important sediment supply processes in mountainous catchments. However, only a few observations have been conducted in the initiation zones of debris flow owing to monitoring difficulties. To detect the behavior of debris flow in an initiation zone, we established a monitoring system in the upper Ichinosawa catchment within the Ohya landslide, central Japan. By analysis of video images obtained from field monitoring, flows that appear during sequences of debris flow surges are classified into two primary types: flows comprising mainly cobbles and boulders, and flows comprising mainly muddy water. The velocity of the muddy flows can be evaluated by Manning's equation. Flows comprising mainly cobbles and boulders have higher flow resistance compared to muddy flows, and cannot be evaluated well by Manning's equation. Furthermore, in the case of muddy flows, it seems the flows are turbulent, whereas flows comprising mainly cobbles and boulders are ordered flow and their boulders slide. Flows comprising cobbles and boulders usually appear at the front of a surge and are followed by the muddy flows. In each typical debris flow surge, the flow depth is highest during passage of flow comprising cobbles and boulders and the flow velocity is highest at the front of the muddy flow. However, some surges are comprised only one flow type. Debris flows in the initiation zone frequently control their volumetric solid fraction by sediment deposition and erosion.

Key Words : *debris flow, flow behavior, field observation, initiation zone, Ohya landslide*

1. INTRODUCTION

Debris flows in mountain streams and ravines can cause severe natural hazards owing to their high velocity, large volume, and immense destructive power. Furthermore, debris flow is one of the most important sediment supply processes in mountainous catchments. To enhance our knowledge of debris flow, detailed field observations have been undertaken in many countries, e.g., Japan1), China2), and Italy3), 4). These observations were mainly conducted in transportation zones of the debris flow, where the entire debris flow is composed of a mixture of sediments and saturated muddy water, and run as a fluidized mass. However, very few observations have been conducted in initiation zones of debris flows (i.e., where the materials start to move5), 6), 7)) because of the extreme difficulties in monitoring within initiation zones. Understanding debris flow initiation and development processes is important for the prediction of debris flow occurrence and the estimation of transport rate in downstream channels. Imaizumi et al.7) identified two types of debris flow based on observations in the debris flow initiation zone on the Ohya landslide, Japan: flows consisting mainly of muddy water and flows consisting mainly of cobbles and boulders. The former flows contain abundant interstitial water, while interstitial water in the surface layer of the latter flows is unsaturated. However, observation data for these two types of flow is fragmentary, and flow behavior (i.e., flow velocity, behavior of particles, deposition and erosion) are poorly understood.

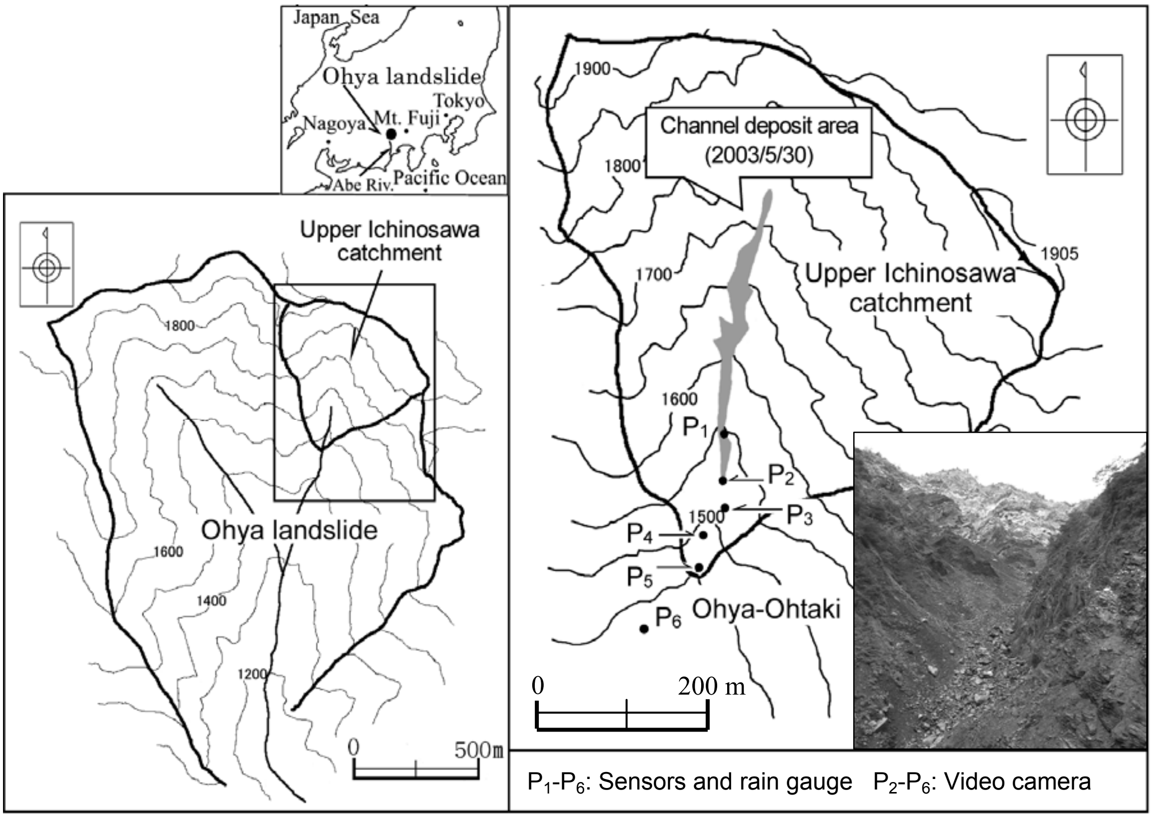

Fig.1 Topographic map of the upper Ichinosawa catchment. The photograph in the figure, which was taken from site P_2 on 4 July 2002, is of the channel deposits around site P_1.

The overall aim of this study is to determine the behavior and development of debris flow in an initiation zone based on field monitoring. We conducted observations for the debris flow initiation zones in the Ohya landslide, one of the most active debris flow areas in Japan. Specific objectives include (i) examining the flow characteristics of the two types of debris flows described above, and (ii) discussing the initiation and development process of debris flow based on field-monitoring data.

2. STUDY AREA

The Ohya landslide is located in the Southern Japanese Alps, central Japan, and is a headwater of the Abe River (Fig. 1). The Ohya landslide initiated during an earthquake in 1707, with an estimated total volume of 120 million m^3 [8]. Unstable material has subsequently been supplied to the old landslide scar and affected the occurrence of debris flow since the original failure. The climate at the site is characterized by high annual precipitation (about 3400 mm) and influenced by orographic effects in the Southern Japanese Alps. Heavy rainfall events (i.e., total rainfall > 100 mm) occur during the Baiu rainy season (from June to July) and in the autumn typhoon season (from late August to early October). The main geologic unit is Tertiary strata comprised of highly fractured shale and well jointed sandstone. Most of the catchment is characterized by rocky sequences with some high, sub-vertical walls; typical gradients of hillslopes are 40˚-50˚.

Most debris flows in the Ohya landslide occur in the upper Ichinosawa catchment (about four events per year[7]); thus, this area is suitable for monitoring debris flows. The highest point of the drainage basin is the east peak (1905 m a.s.l.), while the lowest point is a waterfall called “Ohya-Ohtaki” at 1450 m a.s.l at the south end of the drainage basin (Fig. 1). The total length of the channel is approximately 650 m and the south-facing catchment has an area of 0.22 km^2. There are no anthropogenic influences on debris flow activity in this area owing to the steepness of the site and harsh environmental conditions. Seventy percent of the basin slope is bare (scree and outcrop), whereas vegetation-covered areas (forest, shrubs and tussock) occupy the remaining 30% of the basin slopes.

In the upper Ichinosawa catchment, unconsolidated debris, sand to boulder sized, has accumulated in the channel bed (Fig. 1). Large boulders (> 1 m) are also common in the debris deposits within the channel. The thickness of debris deposits reaches several meters in some sections. Typical channel gradients of the debris deposit area range from 28° to 37°, and range from 36° to 38.5° for talus slopes. Channel gradients range from 16° to 28° between sites P_2 to P_5, where deposition of sediments and bed rock compose the bed surface alternatively. Sediment infilling of steep channels is dominated by freeze-thaw promoting dry ravel because of the steep hillslopes9).

3. METHODOLOGY

The monitoring system was installed in the upper Ichinosawa catchment in early spring of 1998 and included video cameras, water pressure sensors, and a rain gauge7). In this study, we used motion images of debris flows captured by video cameras during daylight hours to discriminate debris-flow occurrences and analyze the flow behavior. We installed two types of video cameras: interval and continuous monitoring cameras. The interval camera captured the channel image for 0.75 s at intervals of 5 min from 1998 to 2001. We changed this interval to 3 min in April 2001 to capture more detail of the flow behavior. The continuous video camera captured images non-stop and was installed at site P_2 in 2003. The continuous camera images were initiated by wire motion sensors installed at several cross sections of the channel. The continuous video camera was moved to sites P_5 and P_4 in 2004 and 2005, respectively. The flow depth and surface velocity of debris flows at 1 s intervals were obtained from video image analysis. The flow depth and velocity were investigated around the point where neither erosion nor deposition was recognized; thus, the condition of the channel beds was defined as a fixed bed. The video image analysis provides surface velocity measurements; however, surface velocity does not represent the mean velocity of all layers of the flow. The mean velocity of all layers of the flow was estimated by multiplying the surface velocity by 0.6, applying the constitutive equation of movable beds suggested by Takahashi (1977). Changes in the cross-section area of debris flow were calculated from changes in the flow depth and cross-section measurement of the channel topography. The discharges of debris flows were estimated from the cross-section area multiplied by the mean velocity of all layers.

4. RESULTS AND DISCUSSION

(1) Flow type

Twenty-six debris flows were captured on video images between April 1998 and October 2004. During the study period, debris flow events on 12 July 2003, 30 August 2004, and 19 July 2006 were captured clearly by continuous video camera. In this study, we mainly analyze video images of these two events to investigate characteristics of debris flows in the initiation zone.

In the upper Ichinosawa catchment, flows that appear in the main flow phase of debris flows are generally classified into two types: flows consisting mainly of muddy water (type 1, Fig. 2d) and flows consisting mainly of cobbles and boulders7) (type 2, Fig. 2c). Type 1 flows are turbulent and are characterized by a black surface due to a high concentration of silty shale. Cobbles and boulders occasionally appear on the surface of type 1 flow. On the contrary, muddy water is almost absent in the matrix of the surface of type 2 flow (Fig. 2e). Type 2 flows are ordered and rotation of large particles rarely observed. It is possible this flow type is defined differently to debris flow in other research11); however, such flows observed in the upper Ichinosawa catchment are the formative stages of debris flows, and this paper treats such type 2 flows as debris flows. Because velocity of the upper layer of the flow is faster than that of lower layer, particles at the upper layer of the head of surges sometimes drop to the front of the surge and are taken into the surge later (Fig. 2e).

Changes in flow depth, velocity, and discharge obtained from video image investigation were compared to changes in debris flow type (Fig. 3); type 2 flows are usually captured at the top of surges determined by abrupt increases in discharge, and type 1 flows tend to follow the type 2 flows. However, a surge captured at 4:49 on 12 July 2003 comprised only type 1 flow (Fig. 3a). On the other hand, clear type 1 flow was not identified by the video camera on 19 July 2006 (Fig. 3c), indicating the order of types of flow is variable. Typical debris flow surges that have preceding type 2 flow and following type 1 flow have the highest flow depth during passage of the type 2 flow and highest flow velocity during passage of the type 1 flow. The highest discharge is observed between the occurrences of the flow depth peak and velocity peak, approximately at the same time as the transition from the type 2 flow to type 1 flow.

(2) Flow velocity

A log-linear relationship roughly expresses the relationship between the flow depth and velocity for the type 1 flow (Fig. 4a); R^2 values of the fitting curves are 0.58 and 0.67 for sites P_2 (12 July 2003) and P_5 (30 August 2004), respectively. Although the local channel gradients of the two sites differ (28˚ for site P_2 and 16˚ for site P_5), the flow depth-velocity relationships are similar. Exponents of the fitting equations for sites P_2 and P_5 (0.714 and 0.620, respectively) are similar to that of the Manning equation (0.667), indicating the flow characteristic of type 1 debris flow is similar to that of water. On the contrary, a log-linear relationship between flow depth and velocity is not clear for type 2 flow (Fig. 3a); R^2 values of the fitting curves are 0.23 0.007, and 0.055 for sites P_2, P_4 and P_5, respectively. Exponents of the fitting equations for type 1 flow (0.104-0.443) are much less than that of the Manning equation, indicating the flow characteristic of type 2 flow differs from that of type 1 flow.

The velocity of type 1 flow is higher than that of type 2 flow for a similar flow depth (Fig. 4a). Because the relationship between flow depth and velocity is affected by various factors (e.g. flow depth, channel gradient, grain size of particle), the difference in flow characteristics between the two types of flow cannot simply be elucidated by a comparison of the flow depth and velocity. To clarify the characteristics of the two types of flows, the relative flow depth (*h* / *d*: flow depth *h* divided by grain size *d*) and velocity coefficient (*v* / *u*∗: flow

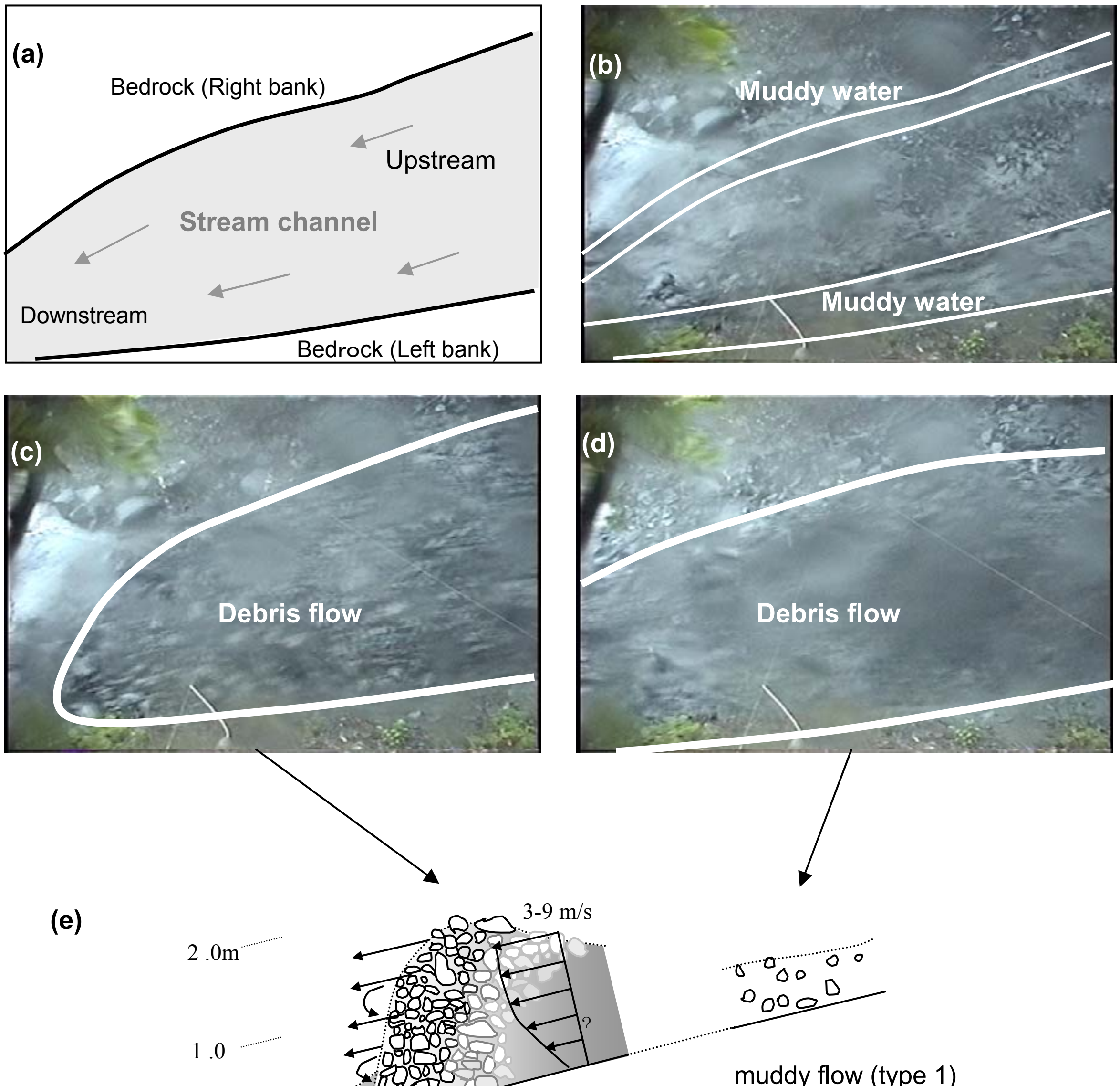

Fig.2 Video images of a debris flow captured at site P_5 on 30 August 2004. (a) Schematic diagram of the view. (b) Video image before arrival of debris flow (16:09:14). (c)Video image when debris flow arrived at left ridge of the view (16:09:16). Flow is comprised mainly of cobbles and boulders and no interstitial water is confirmed in matrix of sediments. (d) Video image of debris flow that are comprised of muddy water (16:09:21). (e) Schematic diagram of longitudinal section of the debris flow.

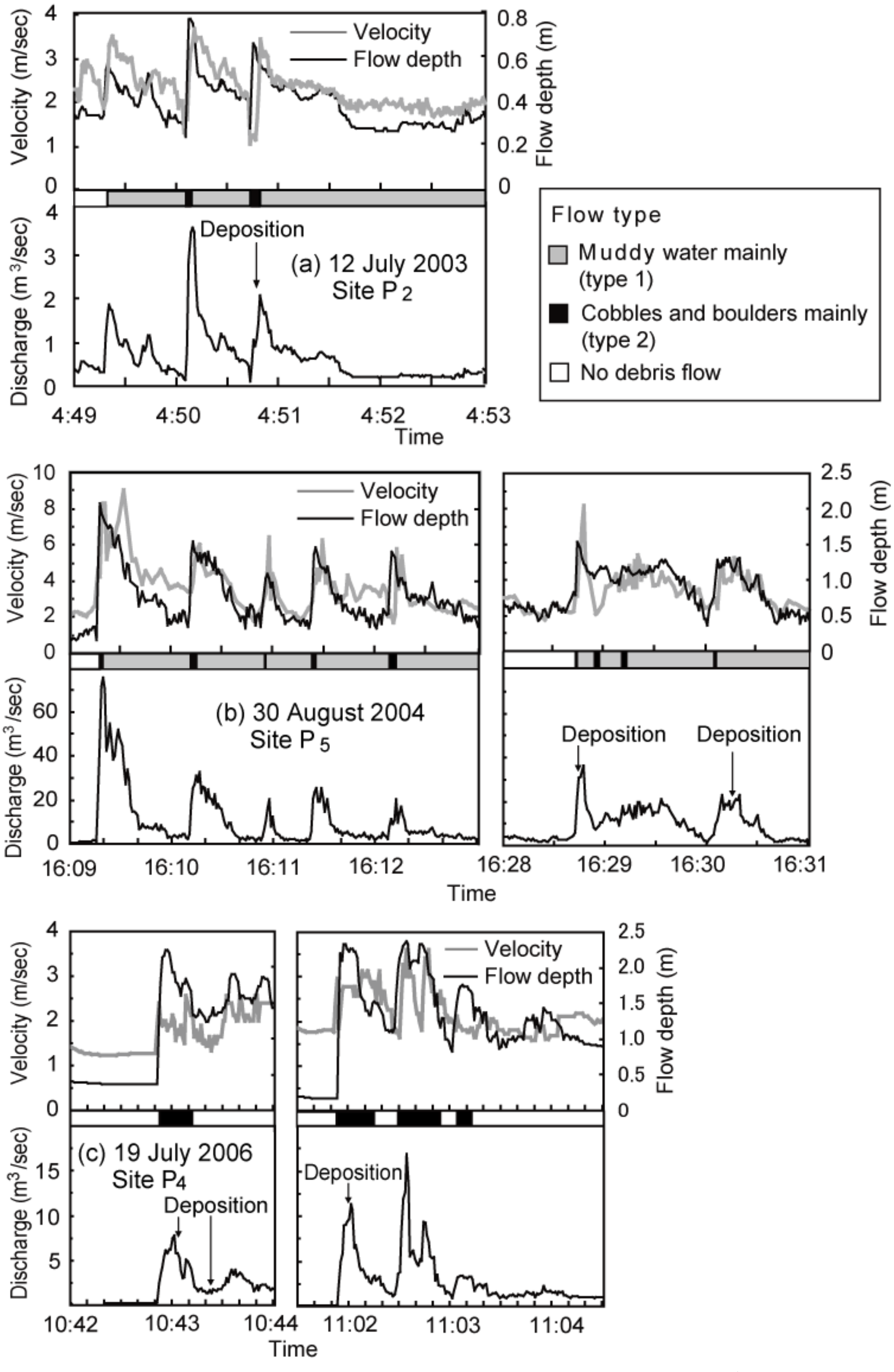

Fig.3 Changes in flow depth, velocity, and discharge during debris flow events: (a) 12 July 2003 7), (b) on 30 August 2004, and (c) 9 July 2006. Changes in type of flow and timings of deposition are also shown in the figures. On 9 July 2006, ordered flows without cobbles and boulders on the flow surface were identified between type 2 surges. Because characteristics of these flows differ from type 1 and type 2 flows, we did not classify flow type of them.

velocity v divided by friction velocity u_*) are compared (Fig. 4b). The median particle diameter of the bed material (0.254 m) is used as d to calculate the relative flow depth. For similar relative flow depths, the velocity coefficient of type 2 flow is less than that of type 1 flow, indicating type 2 flow has larger flow resistance than type 1 flow does. Debris flows having higher volumetric solid fractions have higher flow resistances12). Thus, abundant sediment in type 2 flow may increase the flow resistance. The velocity coefficient of type 1 flow increases with increasing relative flow depth. On the contrary, the relationship between the relative flow depth and velocity coefficient of type 2 flow is not clear because data for type 2 flow is scattered widely. The wide range of volumetric solid fractions of type 2 flow possibly results in the wide range of velocity coefficients for a given relative flow depth.

Because of the higher flow velocity, type 1 flows sometimes get over some part of preceding type 2 flows. Consequently, some cobbles and boulders of the type 2 flows are taken into the following type 1 flows.

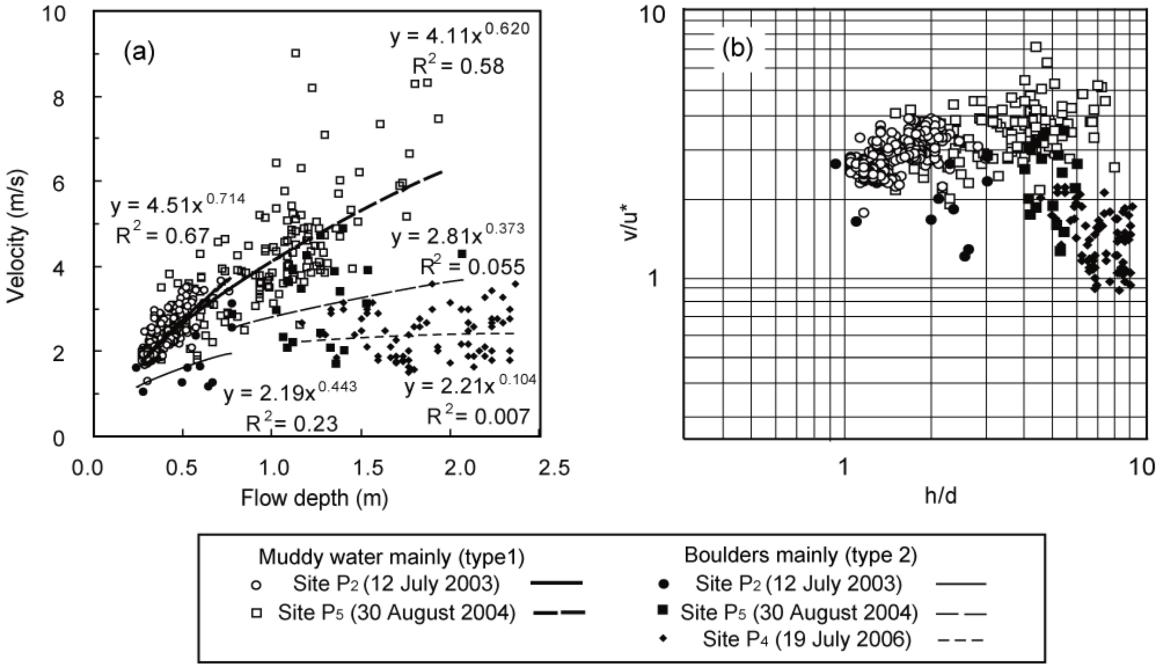

Fig.4 Difference in velocity and resistance law between flows consisting mainly of muddy water and flows consisting mainly of cobbles and boulders. (a) Comparison of flow depth and velocity. Data in the figure are segregated by flow type and observation site. Fitting curves for each flow type and observation type are illustrated in the figure. (b) Comparison of relative flow depth (*h* / *d*: flow depth divided by grain size) and velocity coefficient (*v* / u_*: flow velocity divided by friction velocity).

(3) Deposition and erosion

In the upper Ichinosawa catchment, deposition and erosion occur during the passage of debris flows⁷⁾. Changes in the level of the channel bed surface due to the deposition and erosion of debris flow are sometimes up to several meters. Analyses of interval video images found that degradation and aggradation of the channel bed up to 1 m occur within 5 min.

The deposition and erosion of sediments occur during the passage of both type 1 and type 2 debris flows. Type 2 flows have the characteristic that all layers from the channel bed to the flow surface cease moving in a short time. For instance, during the passage of type 2 flow at 4:50:45 on 12 July 2003 (Fig. 3a), the video image captured the velocity of a section of the flow decreasing gradually and all layers of the section ceased moving in a short time. On the other hand, the termination of movement for all layers was not seen during the passage of type 1 flow. During the passage of type 1 flow at 16:30:15 on 30 August 2004 (Fig. 3b), particles in the lower layer of the flow deposited individually..

5. CONCLUSION

In an initiation zone of debris flow in the upper Ichinosawa catchment, debris flows can be classified into two types: flow consisting mainly of muddy water (type 1), and flow consisting mainly of cobbles and boulders (type 2) 7). Based on our observations, we investigated characteristics of these two types of flows as well as continuous changes in the flow type during a sequence of a series of debris flow events.

The mobility of the flow consisting mainly of cobbles and boulders is poor compared to that of the muddy flow. Some parts of the preceding flows comprised mainly of cobbles and boulders are taken into following muddy flows. Furthermore, erosion and deposition occur during passage of debris flows. Consequently, debris flows in the initiation zone frequently control their volumetric solid fraction by sediment deposition and erosion, and keep running downstream. The hydraulic mechanisms of the two types of flows were not elucidated in this study. Since the hydraulic mechanisms of debris flow are important for the prediction of debris flow occurrence, we need to asses the mechanisms of debris flow in the initiation zone.

REFERENCES

1) Suwa, H., Yamakoshi, T., and Sato, K.: Relationship

between debris-flow discharge and ground vibration. In D. Rickenman & C.L. Chen (eds), Debris-Flow Hazards Mitigation: Mechanics, Prediction, and Assessment; Proceedings of the 3rd International DFHM Conference, Taipei, Taiwan, pp. 311–318, Rotterdam, A.A. Balkema., 2002.

2) Zhang, S.: A comprehensive approach to the observation and prevention of debris flows in China, *Natural Hazards*, Vol. 7, pp. 1–23, 1993.

3) Arattano, M.: On the use of seismic detectors as monitoring and warning system for debris flows. *Natural Hazards*, Vol. 20, pp. 197–213, 1990.

4) March, L., Arattano, M., and Deganutti, A. M.: Ten years of debris-flow monitoring in the Morcardo Torrent (Italian Alps), *Geomorphology*, Vol. 46, pp. 1–17, 2002.

5) Takahashi, T.: Debris flow, IAHR Monograph. Rotterdam: A.A. Balkema., 1991.

6) Berti, M., Genevois, R., Simoni, A., and Tecca, P. R.: Field observations of a debris flow event in the Dolomites. *Geomorphology*, Vol. 29, pp. 265–274, 1999.

7) Imaizumi, F., Tsuchiya, S., Ohsaka, O.: Behaviors of debris flows on the mountainous torrent in Ohya collapse, Japan, *Canadian Geotechnical Journal*, Vol. 42, 919－931, 2005.

8) Tsuchiya, S., Kimura, M., Ohsaka, O., and Tarumi, M.: Debris transport on the steep gully of the mountainous large-scale Ohya collapse, Shizuoka prefecture, Japan. In Proceedings INTERPRAEVENT 1996. Garmisch–Partenkirchen, Germany, Bd. 1, pp. 273–281. Klagenfurt, Tagungspublikation, 1996.

9) Imaizumi, F., Sidle, R. C., Tsuchiya, S., Ohsaka, O.: Hydrogeomorphic processes in a steep debris flow initiation zone, *Geophys. Res. Lett.*, Vol. 33, 10, L10404, 2006.

10) Takahashi, T.: A mechanism of occurrence of mud-debris flows and their characteristics in motion, Annuals Disaster Prevention Research Institute, Kyoto Univ., Vol. 20(B-2), pp. 405–435 (in Japanese with English abstract), 1997.

11) Coussot, P., Meunier, M.: Recognition, classification and mechanical description of debris flows. *Earth-Science Reviews*, Vol. 40, pp. 209–227, 1996.

12) Egashira, S., Miyamoto, K., Ito, T.: Bed-load rate in view of two phase flow dynamics, *Annual Journal of Hydraulic Engineering, JSCE*, Vol. 41, pp. 789–794, 1997.