Sedimentary Structure of Debris in Hollow Deposited during Selective Logging

Noriko Takeshita*, **Yoshimasa Kurashige**** **and Kazuomi Hirakawa****

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I. Introduction

When selective logging was performed in natural coniferous forests in Hokkaido, an unpaved road and connected network of line sites were usually constructed on forest hillslope. During the construction, debris cut by a bulldozer was deposited on the hillslope, in particular in zero-order valleys. Thus, the deposited debris acts as a major source of suspended sediment of a river during a rainfall event (Kurashige and Fusejima, 1997).

During the construction, the debris were pushed out to the downward hillslope from the shoulder of the road or line site for several times at a site. The debris farther fell on the hillslope by gravity until it was stopped by friction. However, the sedimentary structure of the debris deposit was unclear. Thus, in this study, the sedimentary structure of the debris deposited during selective logging was examined in detail in the Hiyamizusawa Brook basin, Hokkaido, Japan.

II. Study area and method

The Hiyamizusawa Brook basin, with an area of 0.93 km^2, is located in a mountainous region southwest of Sapporo City, Hokkaido, Japan (Fig. 1). The geology of the basin is predominantly andesitic agglomerate and quartz porphyry. The slope is under a fir, birch and maple forest. Bamboo grass and osmund are the dominant undergrowth in the forest. Snow lies on the basin from December to April to a depth of several meters. The basin has two major flood seasons in a year, i.e., the snowmelt season from early April to mid-May, and the summer rainy season from mid- August to mid-October. The total annual precipitation is ca. 1400 mm.

An unpaved road was constructed in 1989. Further, selective logging was carried out in the southern part of the basin during the period from May to June 1992 when a bulldozer cut part of the slope in order to construct a line site to remove the logs. During this operation, the debris cut from the slope was deposited on the down-slope surface, in particular in zero-order valleys in the basin (Fig. 1), and this debris is here called the deposited sediment. The surfaces of the line site and the deposited sediment were bare in the summer of 1992, whereas about 50% of those surfaces had been covered with vegetation, mainly butterbur, by the summer of 1995.

The sedimentary structure was examined at the deposited sediment in a zero-order valley

* Environmental Bureau, Sapporo Municipal Office Kita 1 Nishi 2, Chuo-ku, Sapporo 060-0001, Japan

** Graduate School of Environmental Earth Science, Hokkaido University Kita 10 Nishi 5, Kita-ku, Sapporo 060-0810, Japan

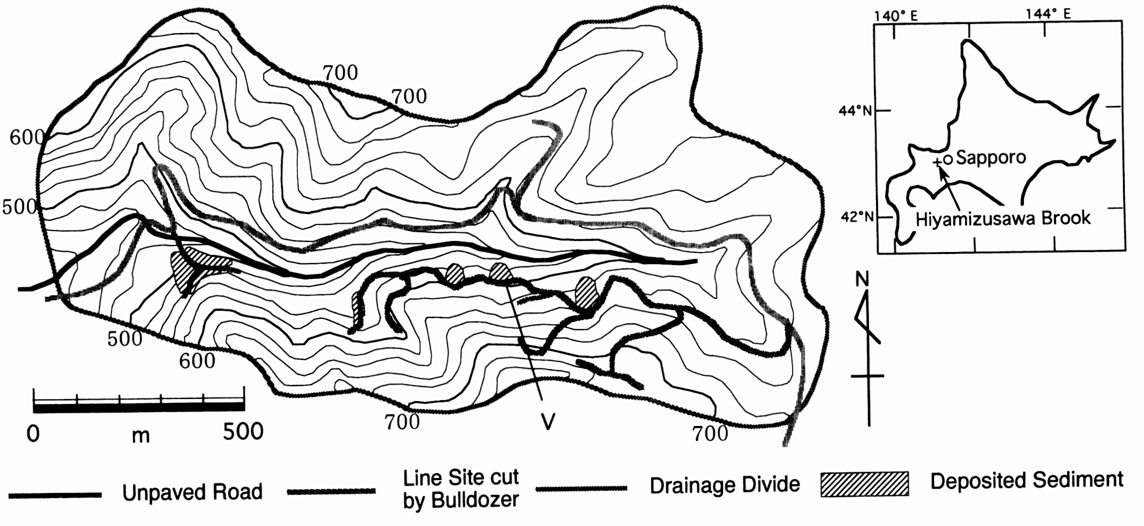

Fig. 1 Map of the Hiyamizusawa Brook basin. Contour interval is 20 m.

(valley V in Fig. 1). Figure 2 shows the geomorphological map of the valley V. The deposited sediment is distributed in an area of about 20 m long and 15 m wide. The relative height from the lower end of the deposited sediment to the upper end was ca. 28 m. Total volume of the deposited sediment was ca. 300 m^3. A gully had been formed on the deposited sediment along the valley bottom during a severe rain on 12 August 1994 (precipitation 113 mm in its duration for 40 min). No perennial current can be found in the gully ; only an ephemeral one during heavy rainfall event.

A trench was excavated by hand with a scoop and a pickax in the deposited sediment from the line site to the gully to sketch the sedimentary structure of the deposited sediment. Here, the base point of the trench was set at the junction with the gully, and all sites along the trench are expressed by the horizontal distance from the base point. At the section upper than 8 m site, the trench was excavated until the buried humus (i.e., the soil surface before the deposition) was exposed. In contrast, at the section below 8 m site, the trench was not be able to be excavated until the buried humus because of the continual collapse of gravel from the side wall. In such cases, however, the depth of the buried humus surface was only measured by eyes.

To sketch the sedimentary structure, meshes of 50 cm long and 50 cm wide were at first set on the side wall of the trench. Further, the position and grain size of each grain were measured by a ruler and the shape of the grain was carefully observed to make a sketch with a scale of 1 : 10 on a 1 mm section paper during the field survey. Only at the section between 4.5 m site and 6 m site, the sketch was drawn based on a photograph of the side wall.

III. Results

The entire sketch of the side wall of the trench is shown in Appendix. Figure 3 shows the schematics of the entire sketch. The representative close-up of the sketch is shown in Figure 4.

At the section from 0 m site to 5 m site (i.e., lower part in Fig. 3), the deposited sediment was composed only of matrix-free coarse materials (10 to 30 cm in diameter). In contrast, at the section from 16 m site to 18 m site (i.e., upper part), the sediment was composed of sand with small

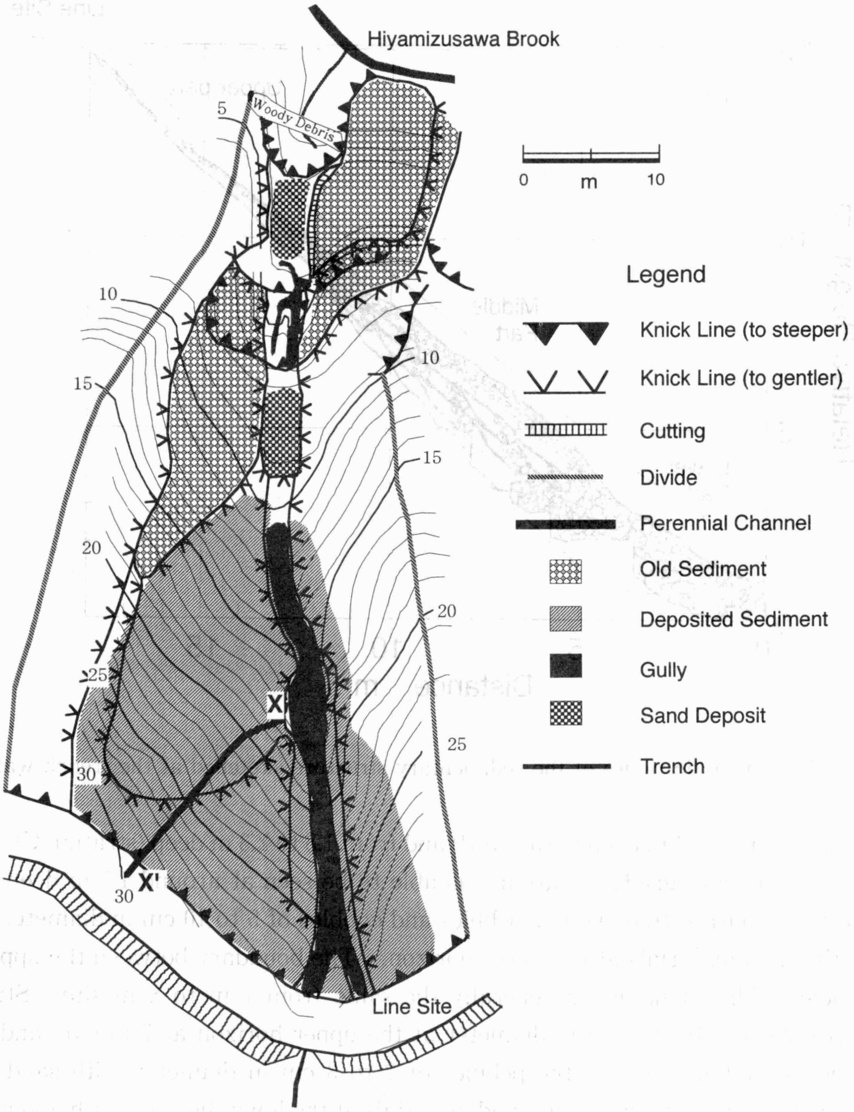

Fig. 2 Geomorphological map of valley V where the sedimentary structure of the deposited sediment was tested. Contour interval is 1 m, and expressed by the relative height from the main channel of Hiyamizusawa brook.

amount of gravel.

On the other hand, clear stratification was able to be seen at the section between 5 m site and 16 m site (i.e., middle part). Each stratum in this section had clear inverse grading structure which is characterized by pebbles and cobbles in the upper horizon of the stratum and sand grains at the bottom (see Appendix and Fig. 3). Each stratum had a characteristic structure also in the slope direction. Coarse materials accumulated at some sites in a stratum, and fine materials exist at upslope of the coarse material.

The representative inverse-grading strata could be seen at the reach around 7 m site (Fig. 4b). Here, three clear inverse-grading strata were formed : from the surface to 0.9 m deep (stratum A

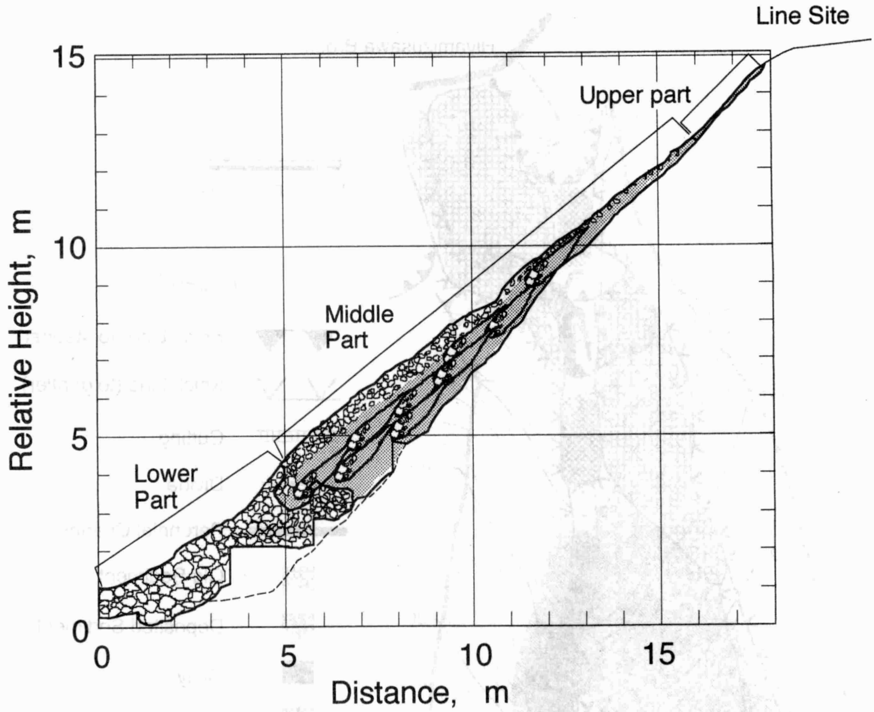

Fig. 3 Schematic figure of the sedimentary structure sketched at the trench wall.

in Fig. 4b), from 0.9 m to 1.4 m deep (stratum B) and from 1.8 to 2.3 m deep (stratum C). In addition, a fairly developed inverse-graded stratum was able to be seen at around 1.5 m deep.

Stratum A has matrix-free angular pebbles and cobbles of 5 to 10 cm in diameter at the upper horizon, and the sand materials at the lower horizon. The boundary between the upper and lower horizons is clear. This structure is generally the same from 7 m to 8 m site. Stratum B has matrix-free pebbles of about 5 cm in diameter at the upper horizon at 7 m site, and it gradually changes to the lower horizon with the pebbles of 2 to 3 cm in diameter with sand materials in matrix. At the 8 m site, stratum B has sand materials at the lower horizon with about 30 cm thick, and it was covered with matrix-free pebbles of the upper horizon. The thickness of sandy lower horizon rapidly decreases as approaches to 7 m site, whereas the thickness of the upper horizon increases. Stratum C has a cobble of ca. 20 cm in diameter at the uppermost horizon, and matrix -free pebbles with 3 to 5 cm in diameter are buried under the cobble at 7 m site. The lower horizon of stratum C at this site has 5 to 10 cm pebbles and cobbles at 2 to 2.3 m deep, and pebbles smaller than 5 cm under the pebbles and cobbles. The matrix of the lower horizon was filled with sand. In contrast, at 8 m site, the upper horizon has matrix-free gravel of smaller than 5 cm, but its thickness was only about 10 cm. The thickness of lower horizon at 8 m site is about 50 cm, and is mainly composed of sand materials. The thickness of sandy lower horizon decreases as approaches to 7 m site, whereas the thickness of gravelly upper horizon increases.

These characteristic features were able to be seen in every stratum of the middle part. Many matrix-free pebbles and cobbles accumulate at some sites in the upper horizon of a stratum, and they adjoin to the sand materials at the downslope direction. Under the matrix-free pebbles and

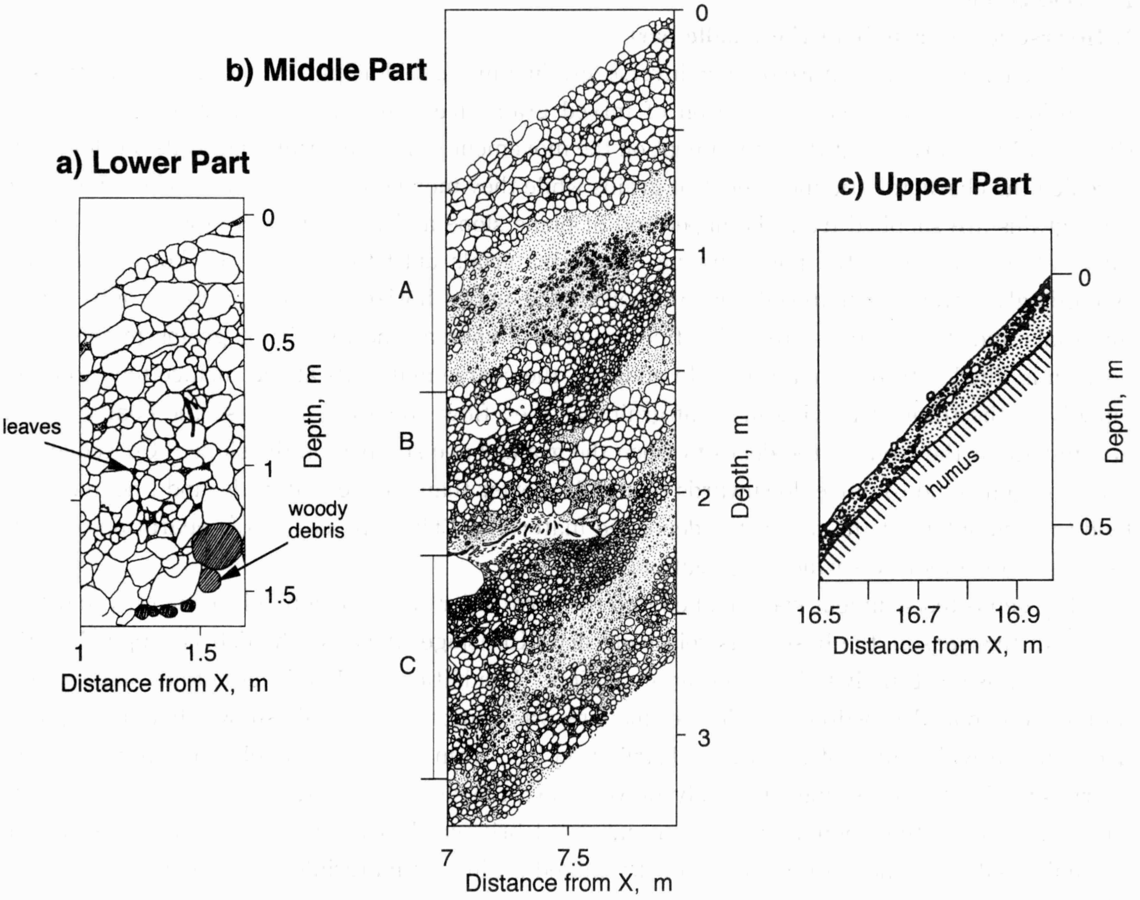

Fig. 4 Representative sedimentary structure at the lower part (left), the middle part (center) and the upper part (right).

cobbles in the upper horizon exists pebbly lower horizon whose matrix is filled with sand. The sandy lower horizon is not clear at around here, but it becomes clear at the sites about 0.3 to 0.5 m upslope from here. At the upslope sites of the stratum, the sandy lower horizon thickens, whereas the upper matrix-free horizon becomes thinner. Finally, the thick sandy horizon adjoins to the pebbles and cobbles at the upslope direction (see Appendix and Fig. 3). Thus, here in this study, a series in a stratum from the pebbles and cobbles at downslope direction to the thick sand material at upslope direction is called the inverse-grading unit.

In the matrix-free cobbles in the lower part, non-decomposed fir leaves and woody debris were found at the lower layer at the section between 1 m and 2 m sites (Fig. 4a). The fir leaves are contained in the horizon deeper than 1 m at around 1 m site, and a large woody debris at 1.5 m deep.

In the upper part, the stratification is unclear (Fig. 4c). At some sections, sand materials tend to accumulate as the lower layer, but its tendency was not so clear as the sand materials in the middle part. The total thickness in this part is about 10 cm.

IV. Discussion

1. Inverse-grading unit in the middle part

The characteristic feature of each inverse-grading in the middle part is very similar to the size separation by free surface segregation of mixed grain-size materials. Drahun and Bridgwater (1981 and 1983) carried out the experiment on the movement of mixed-grain materials on slope, and revealed the characteristic movement of grains while they move down the slope. When the mixed-size grains are supplied from the upper end of plane slope and freely moves downward, the fine materials migrate into the pores among coarse materials until they reach the bottom horizon. Accordingly, after the materials have stopped, the upper horizon is composed of only coarse materials and its matrix is free with fine materials, whereas the matrix of grains in the lower horizon is filled with fine materials. In addition, the coarse materials at the surface tend to move quickly to the front of moving mass of grains as they flow down the slope, so the coarse grains accumulate at the front of the deposits when the grains have stopped on the slope. Consequently, fine materials tend to move downwards relatively slower than coarse materials, and fine materials tend to accumulate at the tail of the deposited materials. These processes of separation of grain-size is termed as free surface segregation.

The deposited sediment was supplied into the zero-order valley by a bulldozer in May and June 1992. In this season, the basin was relatively dry (Kurashige, 1993), so the debris supplied by the bulldozer was most likely to be under dry condition. In addition, the bulldozer cut not only regolith on the slope but also bedrock while the line site was constructed. This shows that the supplied debris had a wide range of grain-size distribution (i.e., from fine sand to cobble). Moreover, the debris supplied from the line site freely flowed down the slope of the zero-order valley. In such cases, the segregation should occur for a mass of debris which was supplied at a time, because it is a universal phenomenon for a mass of dry mixed grain-size materials which flow down a slope (Bridgwater, 1993). Accordingly, after they stopped, the characteristic inverse-grading unit can be found in the deposited sediment.

On the other hand, the bulldozer has supplied the debris into the valley for several times. Consequently, the characteristic inverse-grading unit should appear when each mass of the sediment has stopped on the slope. A number of the inverse-graded units in the middle part were thus judged to be affected by the number of debris supply from the line site.

The similar inverse-grading stratification is reported in debris slopes or debris talus (Ishii, 1988; Ishii et al., 1992). On the middle of these slopes, matrix-free coarse materials can be found at the surface horizon, whereas sand materials or matrix-filled materials exist at lower horizon. Ishii (1988) tested the stratification of debris talus whose sediment was supplied by dry regolith flow, and revealed that fine grains migrate among coarse materials into deeper horizon as a mass of debris is transported. Consequently, an inverse-grading occurs in the talus deposits, and one stratum of inverse-grading structure can be formed by one sequence of dry debris flow. This process is essentially the same as the segregation process.

2. Matrix-free cobbles in the lower part and non-graded sand in the upper part

In the lower part of the deposited sediment, only matrix-free cobbles are accumulated, but no sand materials or matrix-filled materials were able to be found at the bottom layer. Such matrix-free cobbles are also found at around the foot of debris talus (Ishii, 1988 ; Ishii et al., 1992). Ishii

(1988) revealed that the cobbles at the foot of talus were supplied by rock fall. In particular, when debris are transported as dry debris flow, some cobbles at the front of dry debris flow start to move individually, and move farther even if the mass of dry debris flow has stopped. Consequently, only cobbles tend to accumulate at the foot of debris talus. Therefore, the matrix-free cobbles in the lower part of the deposited sediment were judged to be supplied by rock fall, in particular by individual rock fall originated from the front of the mass of sediment flowed down the slope.

In contrast, poory graded thin sand material is deposited in the upper part. Since this layer continues to the sand material at the lower layer in the middle part (see Appendix), we judged that the sediment of the upper part is a tail of an inverse-graded unit in the middle part. This shows that the coarse materials already have transported to the downslope direction and not stopped in this part. Consequently, the inverse grading was not clear in the upper part.

V. Conclusion

The sedimentary structure of the deposited sediment is characterized by a number of strata each of which can be divided into several inverse-grading units. This structure was formed by many sequences of segregation process as mixed grain-size materials were supplied and flowed down the slope under dry condition.

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林業施業に伴う放置土砂の堆積様式

竹下　紀子*・倉茂　好匡**・平川　一臣**

キーワード：逆級層，セグレゲーション現象，混合粒径砂礫，択伐施業

北海道・札幌市近郊の冷水沢支川流域では，1992年の択伐施業に伴い，斜面上にブルドーザーを用いて施業道が敷設された。このとき斜面を切り土して生じた土砂の多くは，流域内の0次谷内に放置された。この作業は流域が比較的乾燥している5～6月に行われた。斜面から切り取られた土砂は，ブルドーザーにより0次谷内へ複数回に分けて排出され，0次谷内では重力により斜面下方へ運搬された。この放置土砂上の最大傾斜方向に水平距離18mのトレンチを掘削し，このトレンチの壁面上に50cm×50cmのメッシュを切り，これをもとに堆積している各粒子の中心位置と形状を計測し，縮尺10分の1のスケッチを作成した。このトレンチ沿いの斜面下部にはマトリックスを欠いた角礫のみが集積した部分が，中部には特徴的な逆級層が複数枚認められる部分が，また上部には砂質の堆積物のみからなる部分が存在した。中部の単一の逆級層に注目すると，上下方向の逆級構造とともに，斜面方向にも特徴的な構造をもっていた。すなわち，斜面上部ほど砂質堆積物に富むのに対し，斜面下部ほど礫質粒子が多くなる一連のユニットが複数存在した。この単一ユニットの構造は，混合粒径砂礫が斜面上を重力落下するときに生じるセグレゲーション現象によって形成されたと解釈した。そしてセグレゲーションにより前面に押し出された礫のうち，さらに転・落石として前方へ移動したものが，斜面下部の礫層を構成したと判断した。

*　札幌市環境局
**北海道大学大学院地球環境科学研究科