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Successive Landslides and Debris Movement in Forested Drainage Basin

By

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活動性地すべり地の変動履歴と土砂生産過程

マルロン　アイパッサ*　　清水　　収*　　新谷　　融*

ABSTRACT

The interpretation of time-sequential sets of aerophotos and field investigations were undertaken to clarify the history of successive landslides, hillslope erosion and sediment movement in stream channels. Major climatic events were mostly responsible for large landslides and were the main process of fluvial sediment transport.

At least 12 large landslides occurred over the 20-year period from 1961-1981 with a recurrence interval between a year and six years in the study site. Most of the subsequent landslides occurred at the site of former landslide scars. Total debris production for these successive landslides was about 60,000 cubic meters of which less than 50 percent entered the main channel. In the Saru River area, voluminous sediment could be produced by deep-seated landslides and transported during major climatic events. On the other hand, shallow debris and creep were mostly delivered from the upslope sites to the main channel in a persistent process. In the Jyurokusen Creek Basin, sediment discharged from landslides could abruptly accumulate in an adjacent downstream channel forming a flood plain during debris torrents.

The response of the channels to landslide debris varied in accordance with the rate of sediment production by landslides and the capability of the river flows to transport landslide debris.

Key Words: Aerialphoto interpretation, deep-seated landslide, landslide recurrence, debris movement, sediment production.

Contents

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Introduction

Where a landsliding has occurred it is important to establish at an early stage the exact nature of the movement, whether the movement was related to any particular phenomenon or not.

An examination of the past history of landslides and also the recent geomorphic processes observed on landslide scars particularly in an area with a potential risk of slope instability, are important in providing significant information for the design of remedial measures to reduce the risk to acceptable levels.

Voluminous landslide debris can be delivered from a hillslope to an adjacent channel or just on the area of the moving hillslope during a single landslide, or a sequence of landslides. Steepness of slope, availability of loose materials and water concentration of the soil could be primary factors affecting slope stability.

In this paper, the history of successive landslides and the movement of landslide debris either on the hillslope or in the stream channel by means of the interpretation of time-sequential sets of aerialphotos and field surveys are discussed.

I. Study Methods

1. Aerialphoto interpretation

Several sets of available aerialphotos of the middle reach of the Saru River (taken in 1956, 1963, 1968, 1974, 1978, 1983, and 1988) and lower reach of the Jyurokusen Creek (taken in 1969, 1974, 1984) were used to describe the histories of the successive landslides. The areas affected by landslides, the expansion of headscarp, the extension of talus on the foot slope, the morphologic features of landslide scars, and the dating of landslides were carefully observed. It was practicable to trace the expression of recent instability by using these series of aerialphotos as they were available for the area over an extended period of time.

It was recognized that landslides and other kinds of hillslope erosion might have occurred before 1956, however, no attempts were made to determine the initial failures. Also landslides were more difficult to recognize in heavily forested areas, and such areas are less accurately mapped than barren ones. In addition to the interpretation of air photos, topographic maps of the studied areas were used for the plotting of data on an individual landslide.

2. Field survey

The identification of recent geomorphological features associated with landslides was undertaken by means of field surveys. This involves an examination of the geomorphologic features of the landslide scar, such as slope ruptures, headscarps, cliffs, the longitudinal slope form, the planar shape of the slope, and deposition areas. Moreover, the nature of overlying debris including the displacement rate of colluvial deposits and the grain size of slope material on scars were observed. In addition to the overall appraisal of geomorphological features, the vegetational aspects related to landslides such as the formation of natural revegetation and the curvature of tree trunks were studied to analyze geomorphological processes such as the areas affected by landslides, the active soil movement, and the chronologic distribution of deposits on the stream channel.

3. Study sites

The study sites lie in north and central Hokkaido (Fig. 1). The first study site is located in the middle reach of the Saru River, about 1.6 km downstream from the junction with the Niseu River (Fig. 2). This river flows from the Hidaka mountain range and ends in the Pacific Ocean. Most of the Saru River Basin is underlain mainly by sedimentary rocks including metamorphic rocks of the Createous period, with sedimentary rocks of the Tertiary period distributed in the riversides of the lower reaches. A dam ("Nibutani Dam") is being constructed on the lower reach of the Saru River to control floods and sediment stemming from two main sources, the upper reach of the Saru River itself and the Nukabira River. Stream-side sliding due to heavy rainfall temporarily occurred in many areas of this basin. Rotational slides frequently combine with flows in compound slides or with lateral spread, producing complex landslides.

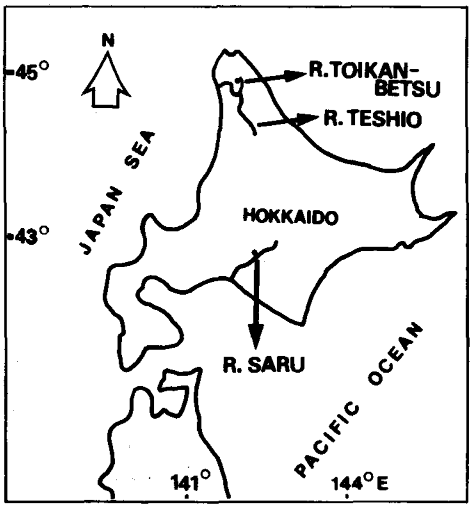


Fig. 1. Location map of study sites.

The second study site is the Jyurokusen Creek Basin (Fig 3), a tributary of the Toikanbetsu River flowing south to the lower reach of the Teshio River which ends in the Japan Sea. Based on its geologic structure, this basin is chiefly composed of sandy mudstone and mudstone which belong to the Neogene System of the Tertiary era. Mixed forest of coniferous and broad-leaved trees are widely distributed in this creek basin. Debris slides and rock falls are widespread along the steep slope sites which are dissected by this creek. Debris slides tend to produce a relatively higher volume of material. They often recur in the same sites and can form a talus cone on the foot slopes. Unlike debris slides, rock falls involve small volumes of coarse material.

The first study site was selected in attempt to describe the accumulation of voluminous

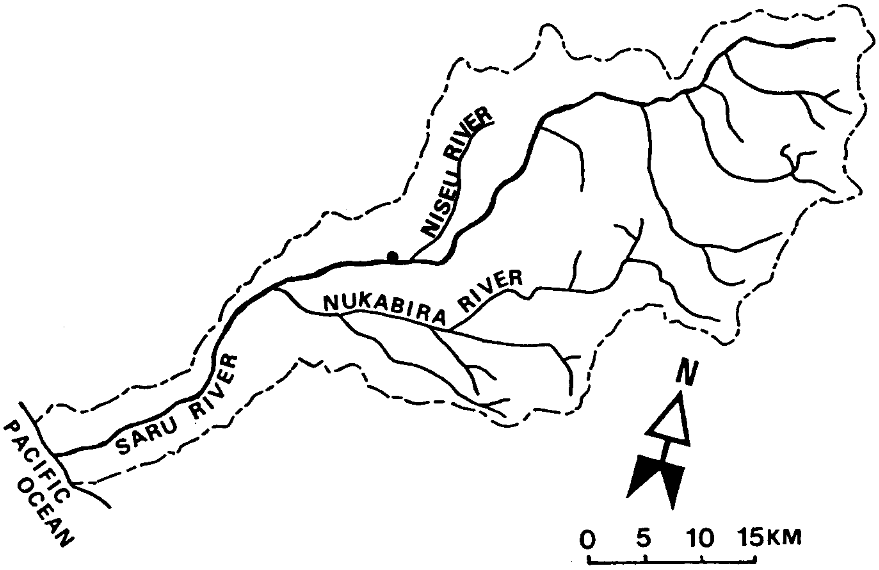


Fig. 2. Study site in Saru River Basin.

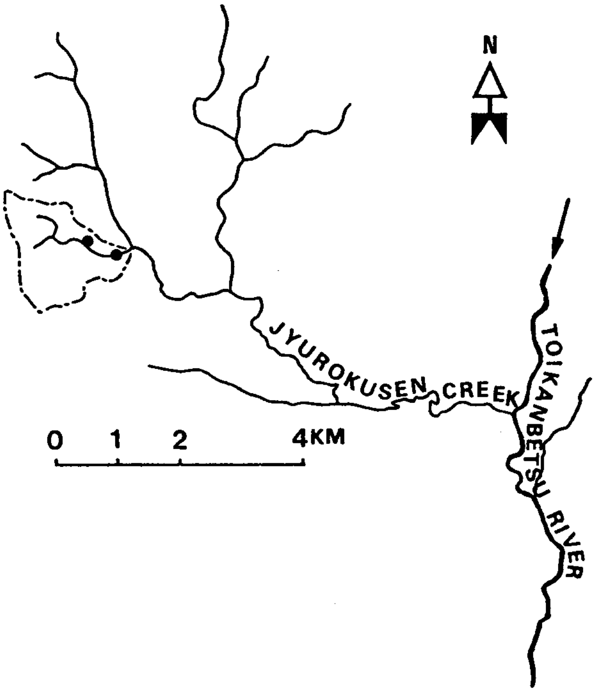


Fig. 3. Study site in Jyurokusen Creek Basin.

landslide debris on the toe of slope which caused a constriction of river channel, while the second study site was chosen since the landslide debris movement on channel in the terms of temporal and spatial aspects could be clearly traced.

II. History of successive landslides

1. Slope failures

Episodic, hillslope surface erosion, shallow and deep-seated landslides, and earth flows are the main types of slope failure in the Saru River area. The intensity of mass movement within a landslide scar is distinctive being strongly influenced by local variations in fracturing and shearing. Shallow slides in colluvial soils are dominant in areas of relatively coherent bedrock, while large deep-seated landslides and earth flows are widespread in more sheared areas.

Basically, the intense deep-seated landslides were initiated by surface erosion. After the occurrence of deep-seated landslides, earth flows particularly on the steep sites of slopes played an important role as a source of debris that moved downslope. Some evidence, however has shown that deep-seated landslides and earth flows have occurred simultaneously as avalanches. These debris avalanches occur on mid or upper slopes and coalesce into the main channel as the material moves downslope. When deep-seated landslides occur frequently, the debris moves downslope and subsequently encroaches on the river channel forming a talus cone, while some colluvium remains perched on the scars.

2. Chronology of debris avalanches

The available aerialphotos and the tree rings analysis were insufficient to date the initial occurrence of landslides. No radiocarbon dating method was applied. Based on the interpretation of time-sequential sets of air photos (Fig. 4) for 32 years (1956-1988), the type of mass movement, the expansion of landslide scars, and the effect of landslide debris on the main channel were chronologically studied. In addition, field surveys have been carried out to examine this site since 1988. Historically, the aspects of the study are systematically described as follows.

Prior to 1956, surface erosion predominantly occurred as the main type of slope failure. Deep-seated landslides also occurred to some extent, particularly on the left slope (Fig. 4a). Through these processes, debris accumulated on the foot slope. The area affected by slope failure was estimated to be about 2.0 hectares.

Based on the aerialphotos taken in 1963, deep-seated landslides were found to be the major type of slope failure. Most of the debris avalanches occurred on mid slopes and coalesced into the main channel directly. A low volume of overlying debris was perched on the scars. The previous landslide debris deposited on the foot slope was mostly washed away by fluvial transport. The transport capability seems to have exceeded the sediment discharge rate from hillslopes. The river valley was widened to a high degree by down cutting as bank erosion continued headward (Fig. 4b). Strong lateral erosion of the river induced the failure of foot slope. It was suggested that the successive storms in the summer of 1961 and 1962 (Table 1) were the major sediment transporting events.

Landslides were estimated to have occurred again in 1966 during a single storm. An extensive deep-seated landslide toward the upslope site was found in the right slope side (Fig. 4c). The north portion of the headscarp was recognized to have retreated about 12 meters. The previous gullies expanded after a large debris flow which was generated

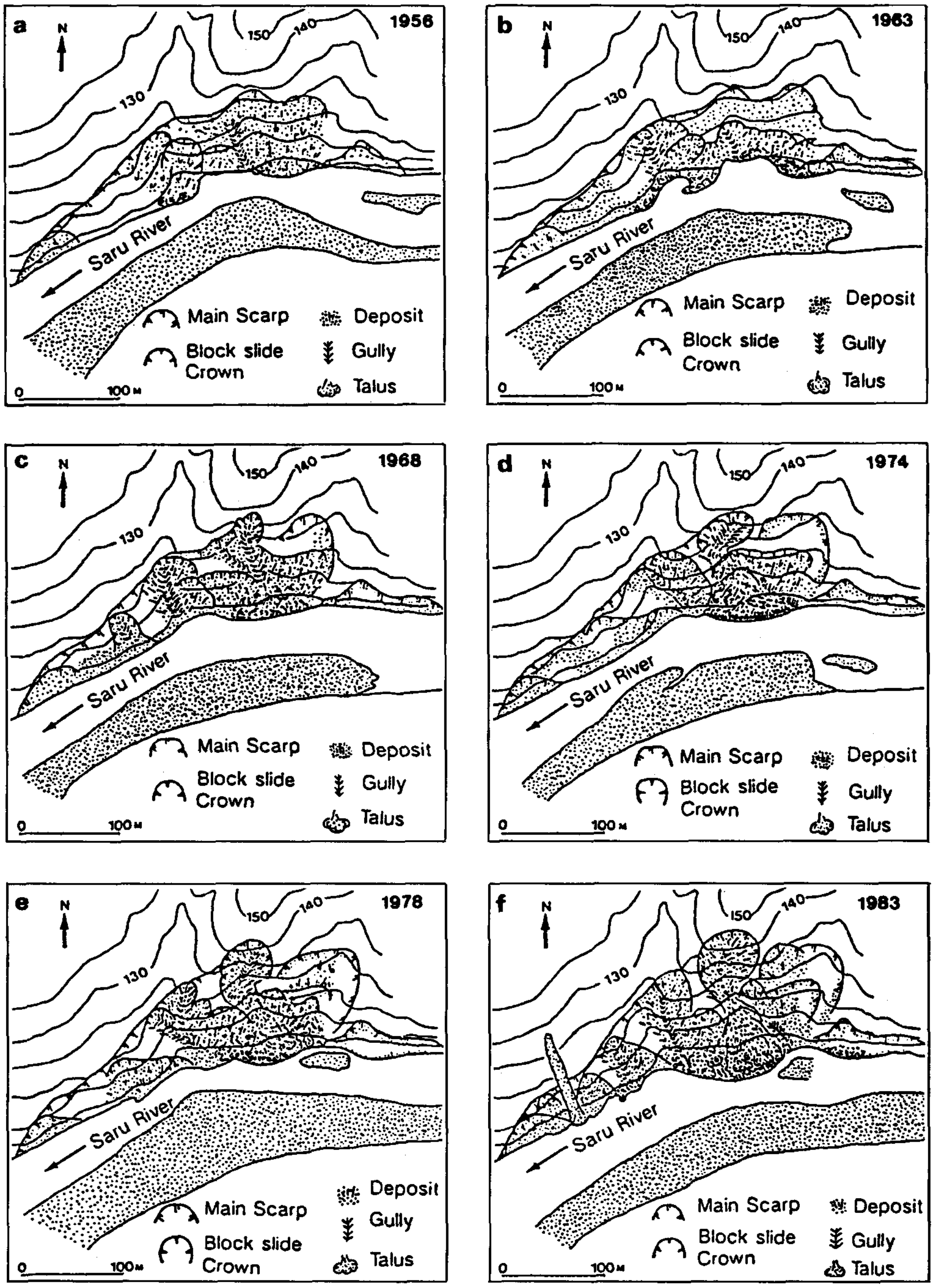


Fig. 4. Landslide scars based on the interpretation of the time-sequential sets of air photos.

Table 1. Historical record of heavy rain in Saru River Basin

No.	Date of heavy rainfall	Max. Successive rain (mm)
1.	September 26-27, 1954	No data
2.	July 3-5, 1955	No data
3.	July 24-26, 1961	274
4.	August 2-6, 1962	248
5.	August 19, 1966	164
6.	October 26, 1970	156
7.	August 17, 1973	173
8.	August 27, 1974	111
9.	August 24, 1975	115
10.	August 5, 1981	132

Source : Hokkaido Development Bureau

from the upper scar to the downslope. Landslide debris moved downslope and accumulated on the foot slope forming a talus cone as large as 1,500 square meters and several meters thick.

The headscarp subsequently enlarged and deepened after successive deep-seated landslides in 1970 and 1973 (Fig. 4d). The former intersecting discontinuity planes were rebuilt into a steeply dipping continuity plane during these times. Gullies continue to be an important source in supplying colluvial soil generated from the upper scar, and result in a rapid and erosive debris flow particularly on the steeper sites of the scar. The total area of the landslide scar became gradually larger (2.6 hectares), affected especially by the deep-seated landslide and hillslope surface erosion.

It was suggested that, due to the successive heavy rains in the summer of 1974 and 1975, deep-seated landslides and shallow slides have repeatedly occurred and resulted in the enlargement of the former headscarp toward the north and east portion (Fig. 4e). The headscarp retreated about 15 meters from the previous scarp. Many deep-seated block slides seem to have occurred in this period. Most of the colluvial soil discharged by these processes accumulated in the foot slope, forming a gentler and larger talus (4,200 square meters).

During the period 1978 to 1983, the major enlargement of main scars, which were from a deep-seated landslide on the center slope and a shallow slide on the right slope as well as a little surface erosion on the left slope (Fig. 4f), were recognized. On the other hand, gullies and swales had continued developing retrogressively on the center and left slopes. The main scar from the deep-seated and shallow slides overtopped about 15 meters towards the north and east portions, respectively.

Moreover, many small block slides widely occurred on the mid-slope. These intense failures, which were considered to have occurred during the 1981 typhoon, discharged voluminous sediment either from the new failures or from the colluvial deposits perched on the scars ; no lateral erosion of the rive seems to have occurred. Consequently, these sediment deposits partly dammed the river channel, forming an areas as large as 5,400 square meters of talus which was distributed widely on the foot slope. Measurement by using the aerialphotos taken in 1963-1983 showed that the colluvial deposits on the foot slope, discharged from the flow area of the center of main scar, had moved at an average of 1.3 m per year in the 15-year period from 1966 to 1981. The area of the scar in 1983 was calculated to be 3.2 hectares. It has gradually grown larger and larger since the first major enlargement in 1970-1973.

3. Zonation of mass movements

Neither the major enlargement of failure areas nor new landslides have been found since 1981. Based on the appearance of young trees on the talus area, it was recognized that this area had remained unchanged. No heavy rain has been recorded since that time, however, active surface and shallow slides of uncompacted debris were still found on the steeper sites of scars.

The profile of the landslide scar based on the aerialphotos taken in 1988 is shown in Fig. 5. In the sense of debris movement and of slope morphology, at least three definite areas of landslide scars could obviously be distinguished under the present condition (Fig. 6).

Firstly, the failure area, "A", is mainly located on the upper slope forming a concavity plane. During the successive failures, the slide mass rotated backward so that the slope of the upper surface of block was diminished, while the displaced soils formed a block which slipped down along a parallel slip surface, leaving a sharp cliff on the summit of the

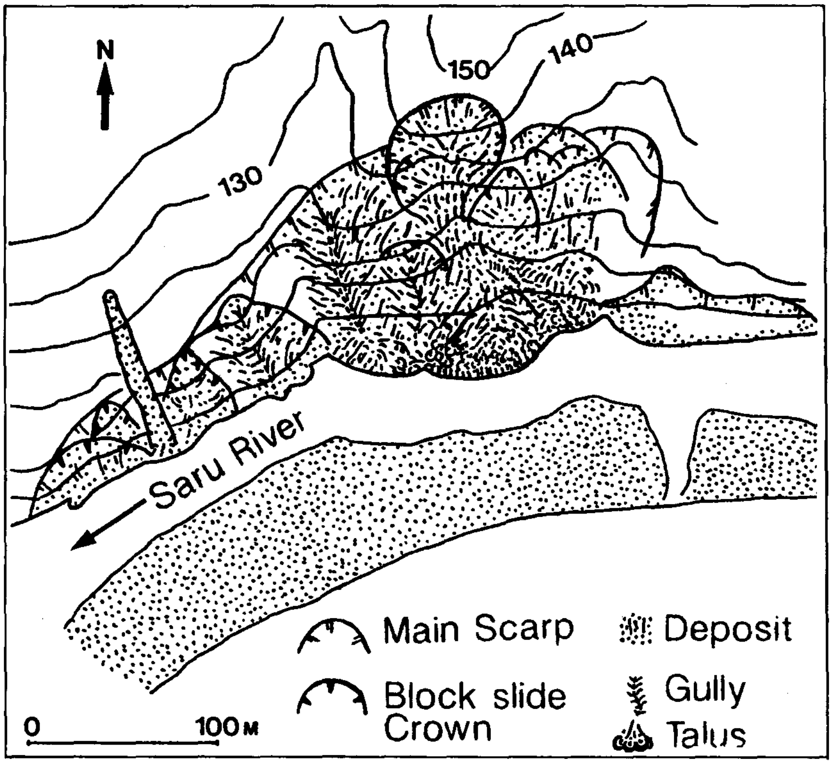


Fig. 5. Vertical view of landslide scar, based on the interpretation of air photo taken in 1988.

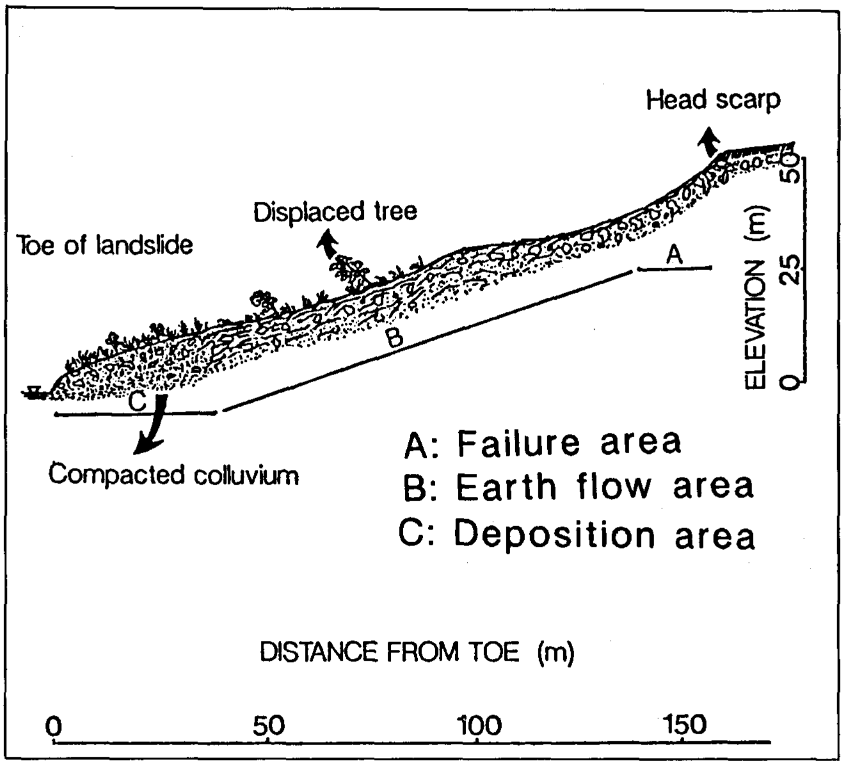


Fig. 6. Longitudinal profile of landslide scar showing mass movement zonation.

main scar. In the area of the largest deep-seated landslide, the failure area might have reached an area of about 0.3 hectare with a 40 meter failure-plane length. Cliff became gradually steeper as the scar overtopped, dipping at an inclination of around 43 degrees. The steep-sided inner scar reached a maximum depth of 5 meters, and it consisted of 4 meters of thick sandy soil and a meter thick of stratified gravels as an upper and lower layer, respectively. Deep gullies, swales and scarps were formed in this area. The larger deep-seated landslide, however, was considered to be the primary source of sediment.

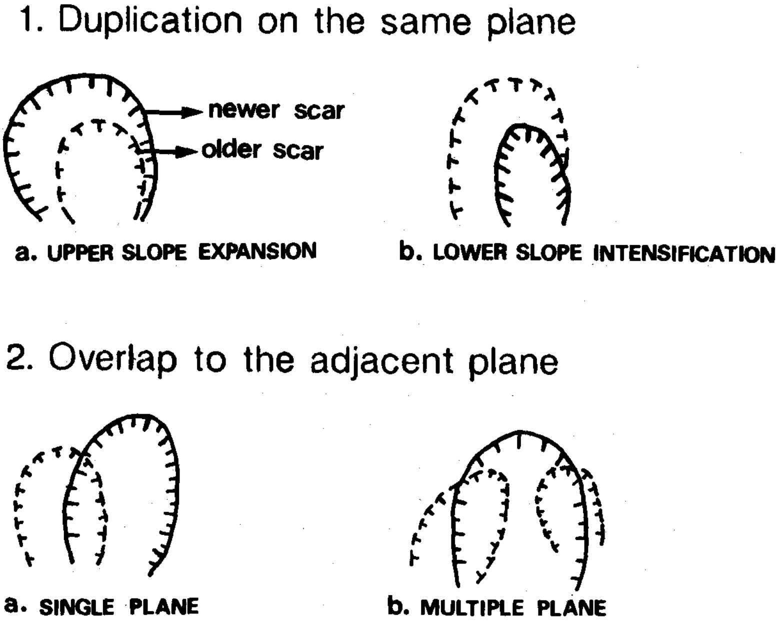
Secondly, the earth flow area (shown as "B"). The landslide debris, which mostly consists of uncompacted clay fill, then moved downslope as a viscous mass, particularly on the steeper sites of the scar. In this area, many young pioneer tress were displaced by the active flow which was generally accelerated by the increased water content of the mass during heavy rains or by the thawing of snow cover. The displacement of colluvial deposit on this area was measured by installing several red-painted wooden stakes (30 cm height) which were embedded vertically into the ground surface. The distance from each stake ranged from a meter to 2.5 meters. The displacement was measured with reference to the markers embedded in the ground surface. Based on the measurements obtained for a one year period (1988-1989), the values ranged from 60-70 cm during the snow thawing and rainy periods (ground slope: 21 degrees). It was suggested that the displacement of colluvial deposit in this area could have been greater in the past decade during the heavy rain periods. Since 1966, the end of the older lower gully was gradually filled with a huge colluvial deposit from the failure area, and this deposit was transmitted downslope as rapid and erosive debris flows. The maximum length of the earth flow area was about 80 meters.

Thirdly, the deposition area is shown as "C". The landslide debris was transmitted through the earth flow area and finally accumulated in the gentler slope that was located in the foot slope, forming a terraced-shaped talus, with some of the debris damming the adjacent main channel. The materials in this area consisted of compacted colluvial. The displacement of debris was relatively slower (4-6 cm) than that in the earth flow area. The maximum length of this area was about 40 meters with a 16-degree average inclination. Most of this area has been covered with bushes and young trees which most likely invaded the area sometime since the latest storm in 1981. In many parts of the landslide scar, the slope was still bare, mostly steep, and composed of deeply weathered parent material which was sensitive to failure.

III. Recurrence types and magnitude of landslides

1. Landslide recurrence types

Based on the time-sequential set of air photos, large landslides frequently occurred in the period 1961-1981. At least about 12 large landslides were found to have occurred in this period. Major climatic events were considered to be the factor triggering these large landslides. Most of the areas having previous landslide scars area prone to subsequent failure. The new failures occur as the reactivation of older phenomena. It was con-



1. Duplication on the same plane

a. UPPER SLOPE EXPANSION

b. LOWER SLOPE INTENSIFICATION

2. Overlap to the adjacent plane

a. SINGLE PLANE

b. MULTIPLE PLANE

Fig. 7. Types of landslide recurrence (simplified from Shimokawa, E. 1984)

sidered probable that many of the scars would have gradually expanded as time passed by. Two types of landslide recurrences could be broadly classified (Fig. 7). Firstly, the subsequent failure might occur in the older failure as a" duplication on the same plane". It might expand toward the upper slope (1a) or on the contrary, it might be just in a part of the lower slope of the older failure (1b). Secondly, the following failure might partially "overlap to the adjacent plane" (2a) or it might also partially overlap several smaller older scar planes (2b) regardless of the position on the former slope (either upslope or lower slope).

These phenomena might be most likely related to the water concentration of the soil and topographic conditions. Some failures are initiated in partially filled hollows. These unchanneled swales are typically filled with a regolith several meters thick. As a result of their subsurface topography, hollows concentrate abundant water, developing high pore pressures which can finally lead to failure of the soil mass. They might also be related to faults or cracks which were irregularly distributed among or on the older scar plane. These faults and cracks break the strata and accelerate the weathering process. Eventually, they provide a space for storage and movement of ground and underground water, which lead to failures.

2. Magnitude of landslides

1) Enlargement of landslide scar

Due to successive heavy rains in 1961 and 1962, voluminous debris was produced by deep-seated landslides which occurred mostly on the mid slope. The maximum length of the main scar was about 72 meters, being shorter than the previous one (Table 2). This might be caused by the intense lateral erosion of the river which washed out a large amount of either the previous debris perched on the foot slope or the debris produced during the landslides of these times. Moreover, it was recognized that the head scarp did not overtop.

Subsequently, the scar became longer (92 meters after the occurrence of landslides during the single storm of 1966. This landslide caused the expansion of the upper scar and the extension of the foot slope. It was found that although the amount of failure debris was smaller than that of the previous one (1961, 1962), the area of talus on the foot slope was 6 times larger than the former one. The ability of fluvial transport was suggested to be insufficient to remove the voluminous debris from the hillslope given the rapidity with which it had been discharged. As a result, an accumulation of debris has remained on the

Table 2. Scar area affected by landslide

Time sets of air photo	Time of landslide	Type of landslide recurrence	Total area of landslide scar (ha)	Max. length of☆ main scar (m)
1956	Prior to 1956	unknown	2.0	84
1963	1961, 1962	1a	2.1	72
1968	1966	1a, 2a, 2b	2.3	92
1974	1970, 1973	1a, 2a, 2b	2.6	100
1978	1974, 1975	1a, 1b	2.8	122
1983	1981	1a, 1b	3.2	160
1988	No landslide	No landslide	3.3	160

☆Maximum length of main scar here is referred to the distance from the upper scar to the river bank.

foot slope.

Expansion of the headscarp and extension of the foot slope were found during the next period of successive heavy rains (1970, 1973, 1974, 1975). The latest occurrence of a major landslide was in 1981. The headscarp retreated 15 meters towards the upslope site. The total scar area after the latest landslide amounted to 3.2 hectares. Since that time, no other major landslide was found. The expansion of headscarp and the extension of foot slope by the successive landslides is shown in Figure 8.

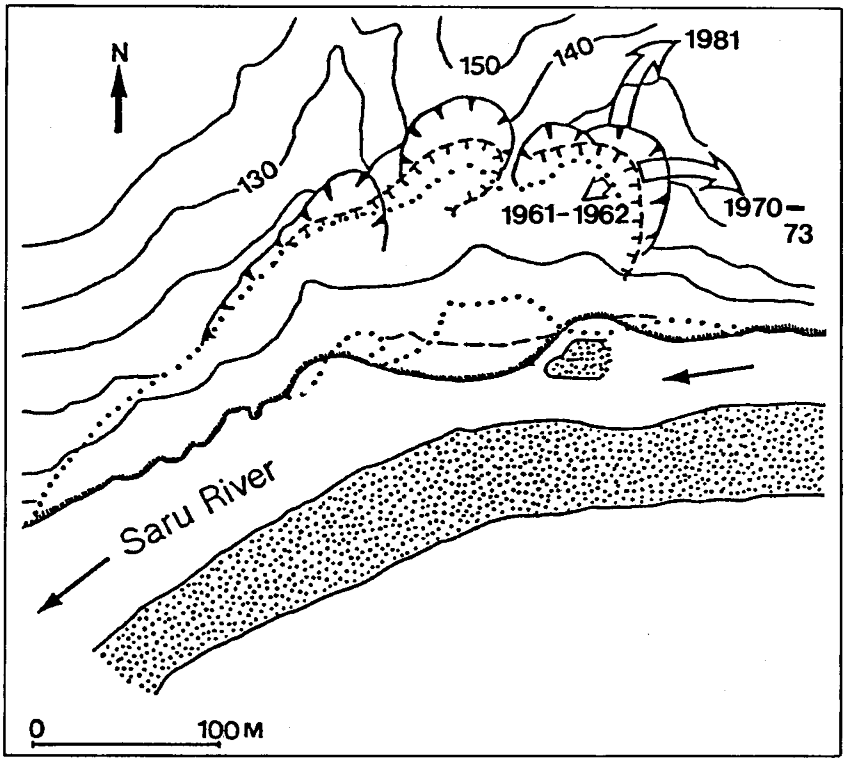


Fig. 8. Expansion of headscarp and extension of foot slope by successive landslides.

Several types (1a, 2a, 2b) of landslide recurrence were found during the storms of 1966, 1970 and 1973. However, upper slope expansion (1a) was found to be the most frequent type during the successive landslides and was the single type of landslide recurrence in the storms of 1961 and 1962 . These landslide recurrences have been the cause for the length of the main scar to have gradually become longer and longer. The landslide debris, moreover, accumulated on the foot slope, moving rapidly into the main channel during the times of landslides without the intense lateral erosion of the river.

2) Sediment production by landslides

The area of scars formed by hillslope failures and the area of debris deposits located on the foot slope could be accurately calculated by means of the interpretation of time-sequential aerialphotographs. However, the difficulty of determining the precise thickness of the earth mass produced by landslides and of the debris deposition has been a continual problem in attemps to measure the volume of landslide debris.

Based on the field surveys undertaken under the present geomorphologic conditions, it was assumed that the earth mass produced by deep-seated landslides and surface erosion (including shallow slides) were similarly distributed with an average thickness of 3 meters and 0.5 meter, respectively. Consequently, the volume of landslide debris could be roughly estimated (Table 3). Based on the recent field measurements, the thickness of landslide debris which accumulated in the foot slope could also be determined. The values ranged from 2.5 to 8.0 meters, averaging about 5.2 meters.

Table 3. Sediment production by slope failure

Time of landslide	Total area and debris volume affected by slope failure					
	Surface erosion		Deep-seated slide		Cum. vol. in foot slope	
	area (m²)	vol. (m³)	area (m²)	vol. (m³)	area (m²)	vol. (m³)
Prior to 1956	12,000	6,000	4,800	14,400	670	3,500
1961, 1962	400	200	5,800	17,400	300	1,600
1966	400	200	3,600	10,800	1,500	7,800
1970, 1973	500	250	3,400	10,200	2,000	10,400
1974, 1975	900	450	3,600	10,800	4,200	22,000
1981	1,600	800	4,400	13,100	5,400	28,000
No landslide					5,500	28,600

Since the relation between the frequency of storms and of landslides was not well understood, the frequency of landslides could not be accurately assigned. The debris volume shown in Table 3 is considered to be the sediment production discharged by landslide ineternally over the studied period.

Frequent high-intensity storms of short duration (Table 1) were most likely the forcing factor for these successive landslides. Slope failures occur during heavy rains, either on the bedrock-colluvium contact or above a denser and more clay-rich layer in the colluvium.

In the heavy rainstorm of 1961 and 1962, about 17,000 cubic meters debris was produced by deep-seated landslides which occurred mostly on the mid slope. Most of the debris was carried by the river flow. A little of debris was perched on the foot slope.

About 10,000 cubic meters debris was discharged by a deep-seated landslide in the single heavy rainstorm of 1966. Most of the debris moved downslope and deposited in the foot slope forming a talus. It was recognized that about 10,000 cubic meters of debris subsequently was produced by deep-seated landslide during the successive storms of 1974 and 1975. After the 1981 landslide, no large amounts of debris have been delivered to the talus area, even when deep-seated landslides produced voluminous debris.

Total debris production by successive landlides since 1961 has been about 60,000 cubic meters. While about half of this debris accumulated on the foot slope, the half either was still perched in the scar or had entered the main channel from the scar.

IV. Landslide debris delivery

1. Dating and magnitude of landslides

Debris slides are the main type of slope failure and were found to be widespread along the steep slope sites dissected by the Jyurokusen Creek. Based on analysis of the growth rings of the pioneer trees on the landslide scar, the times when landslides occurred were determined. Two groups of natural even-aged forests were found in the landslide scar (Fig. 9). Their presence indicated that landslides had repeatedly occurred at two different times. The older landslide was estimated to have occurred in 1962. The scar area stripped by the landslide was about 4,500 square meters with a relatively thinner sliding depth. The average horizontal distance of the slope was 70 meters, dipping 38 degrees. If landslide debris moved with a sliding depth of 2 meters, the volume of debris could roughly be calculated to be as large as 9,000 cubic meters (Table 4). It was suggested that this landslide was triggered by heavy rain (more than 100 mm) on September 1, 1962. Most of the sediment discharged by the landslide was perched on the scar.

Subsequent landslides were considered to have repeatedly occurred on the same slope plane as the previous one in 1973. The area affected by the landslides were relativelly small (2,000 square meters). The debris moved with an average sliding depth of 1.5 meters.

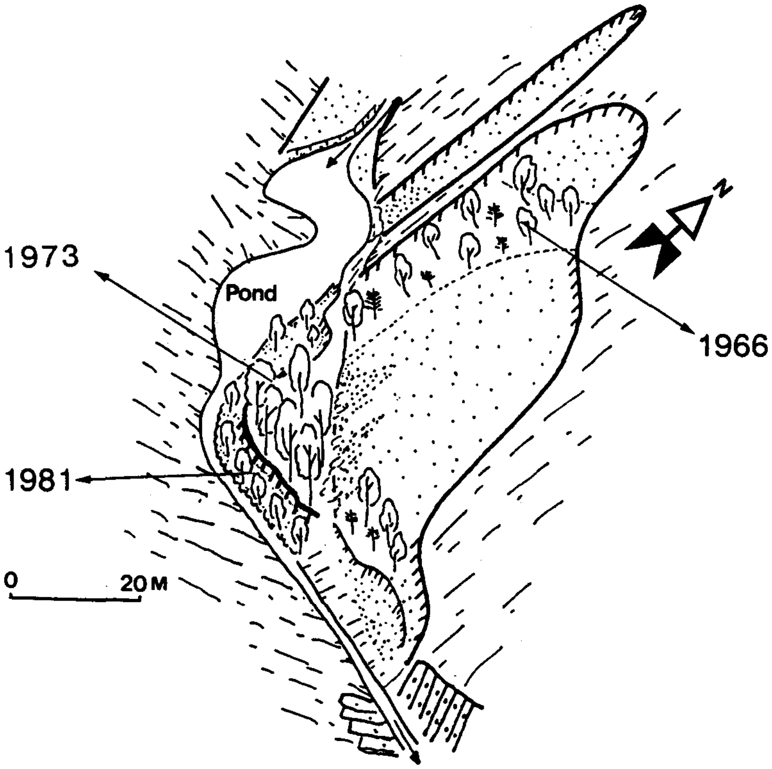


Fig. 9. A typical debris slide found in the Jyurokusen Creek (Shimizu, O. and Aipassa, M. 1988).

Table 4. Sediment production, observed on the lower reach of Jyurokusen Creek

Time of torrent	Sediment produced by landslide		Location of sediment deposition	
	area (m^2)	Vol. (m^3)	Landslide scar (m^3)	Stream channel☆ (m^3)
1966	4500 m^2	9,000	?	No definite indication
1973	2000 m^2	3,000	760	1.800
1981	–	–	No definite indication	1.500

Note: ☆is reffered to the flood plain site which is situated about 150 meters from landslide scar.

This landslide activity probably occurred during the heavy rains recorded on August 17-18, 1973. Most of the landslide debris was transported to the adjacent downstream channel. A little deposit dammed the creek channel resulting in the formation of a small pond.

There were heavy rains (more than 100 mm) on August 3-6, 1981 recorded in the neighbouring area (Nakagawa Town). No major landslide was found in the previous scar at this time. However, some of the older deposits which accumulated on the foot slope had been transported to the downstream channel. It was suggested that the exposed rock fall sites located beside the landslide scar might have been an important sediment source during that time. The weathered overlying debris was mainly composed of coarse, unconsolidated and friable materials having increasingly poorer compaction characteristics. The size of the materials varied mostly from 2 to 20 mm (Aipassa, M. and Shimizu, O. 1988). The weathered overlying materials on the scar is shown in Figure 10. The feature of the slope after sliding is mainly characterized by the presence of an extensive rectilinear section (straight in profile). Debris avalanches are typically rapid and more

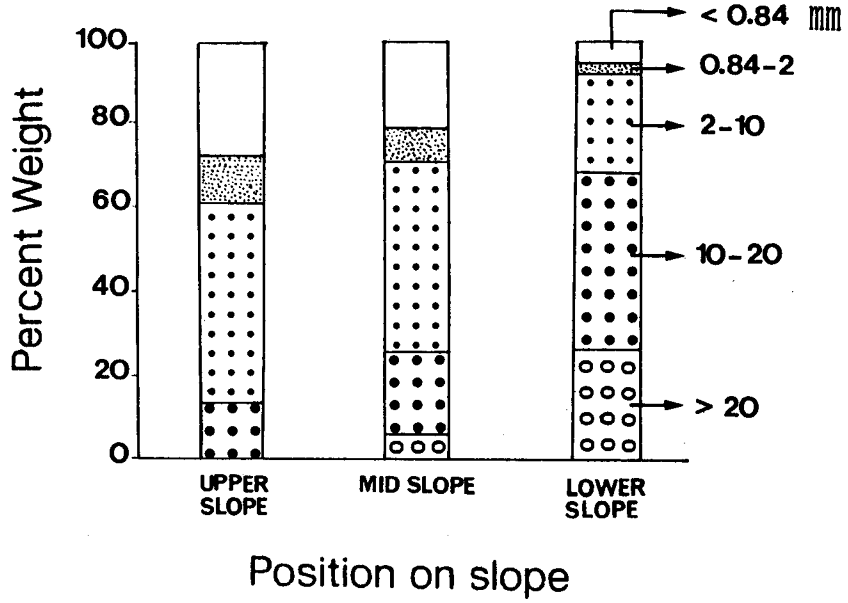


Fig. 10. Particle size (mm) of overlying debris.

abrupt being in the form of separate grains. In the upper scar, the mass was detached so completely that bedrock was exposed which led to the formation of a cliff.

2. Distribution, movement and volume of sediment in channel

Figure 11 shows the general description of the landslide sites, rock falls, and flood plain morphology in the lower reach of Jyurokusen Creek Basin. Besides debris slides, rock falls also supply sediment into this creek.

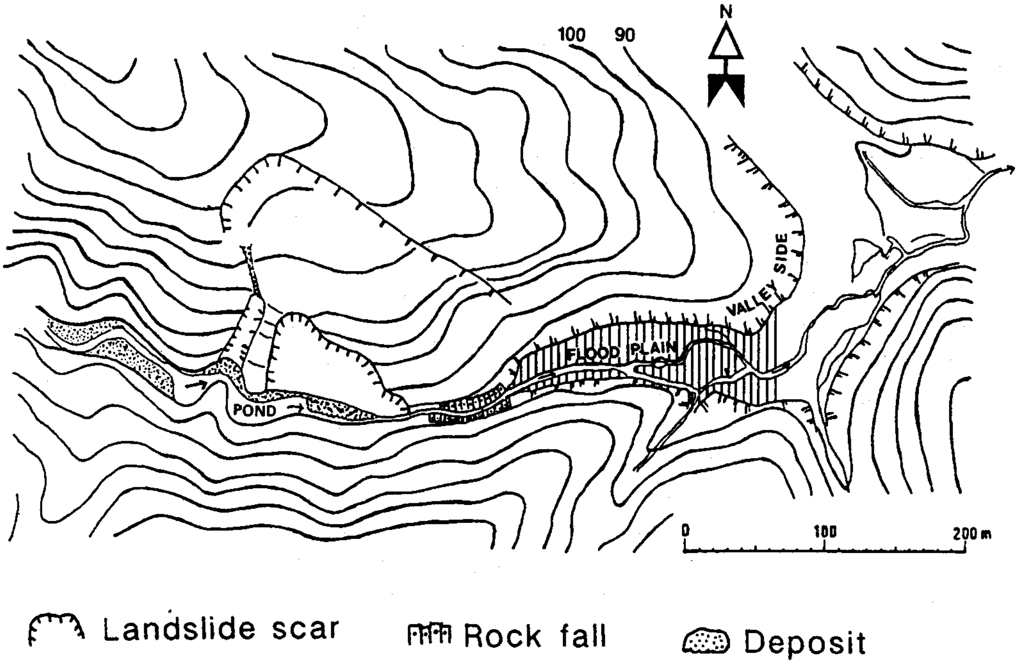


Fig. 11. Topographic map of the lower reach of Jyurokusen Creek.

The growth rings of trees on the flood plain were used to determine the age of forests or deposits. The forests were found to be uniform in age (Aipassa, M. & Shimizu, O. 1989), this finding was used to determine the deposit distribution in terms of its spatial and temporal aspects. Cross sectional profiles of the stream bed were measured in an attempts to estimate the sediment volume.

1) Distribution of sediment in channel

Based on age of deposit and elevation of surface morphology, the flood plain could generally be divided into two distinct areas (Fig. 12).

The lower area was mostly occupied by the older deposit (16 y). The elevation of horizontally bedded deposit in this area is lower than that of the upper area. This deposit was widely distributed, its length being about 190 meters. The average thickness of the deposit was 0.4 meter. In this area the stream-bed material was composed of coarser and finer surface materials. Most of the coarser surface materials existed in the upper site of this deposit area. This material had presumably been sorted out from the finer material and left as a residual accumulation since it was not readily transported. The finer surface materials were mostly carried farther, either as a thinner layer or a vertical accretion

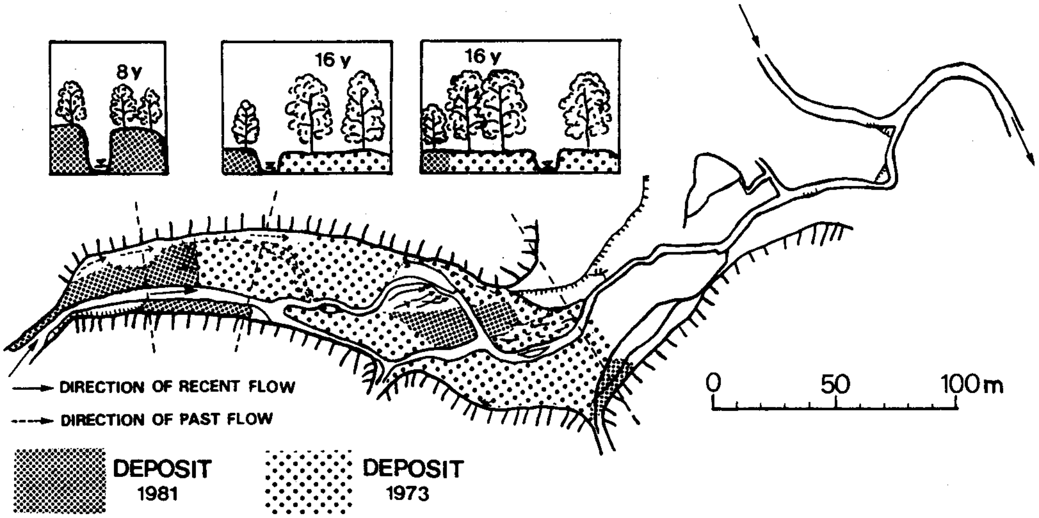


Fig. 12. Distribution of deposit on overloaded channel, based on tree age.

deposit over the entire flood plain surface of the lower site.

The higher area was covered by the newer deposit (9 y) which was found to be thicker (1.1 meter average). This area was established primarily as a deposit bedding above the water level. The surface material of this area was finer and gradually grew coarser vertically approaching the water level.

2) Movement and volume of sediment in channel

The sediment stored up in these two deposit areas was assumed to be closely related to the heavy rainfall events which occurred in 1973 and 1981. During the 1973 storm, the sediment discharged by landslide was mostly transported from the area of the moving hillslope to the adjacent downstream area. The debris torrent was assumed to be faster when passing the narrow stream. The transport velocity became gradually slower when they entered the wider valley floor area. The storage capacity in this area was relatively high so that the debris flow was widely distributed with a thinner stream-bed elevation. The volume of deposit in this area was estimated to be about 3,000 cubic meters (Table 4).

During the heavy rainfall in 1981, it was recognized that the sediment production was smaller (1,500 cubic meters) than that in 1973. No major sediment production was discharged by landslides to the stream channel. However, it was recognized that some sediment production was supplied by rock fall located near the landslide scar. Besides this, it was suggested that some older deposit which had rested on the foot slope of landslide scar was carried downstream at this time. However, the transport capacity during this time was suggested to be relatively slower so that the debris flow could not be washed as far as at during the storm 1973. The stream channel is relatively narrow in this area, and since the transport capacity was relatively slower, the sediment was not readily delivered to a longer distance. Consequently, it accumulated in narrow areas forming a thicker deposition (Fig. 12) and causing the channel to shift to a new course.

In terms of spatial and temporal aspects, the sediment filled regressively to the upper area after spreading widely over the lower area. In other words, the locus of deposition progressed from the lower area to the upper area. In the summer of 1988, a small volume of sediment (less than 100 cubic meters) was discharged by rock fall. Most of it was perched on the foot slope, while a little of the sediment entered the stream channel system. Rock falls were suggested to have frequently supplied sediment into the channel even during times without heavy rain. The steepness of rock fall sites and the uncompacted slope material seem to be the agents of failure.

V. Response of channel to landslide debris

Based on the field investigation and the interpretation of the time-sequential sets of air photos, the response of the channel to landslide debris was roughly determined in terms of the rate of sediment production by landslides and the capability of the river flow to transport landslide debris. Several types of channel response to landslide debris were broadly explained in Fig. 13, 14.

When the capacity of the river flow to remove the landslide debris from hillslope was relatively higher, substantial widening of the valley floor could result (Fig. 13a). This phenomenon could be clearly seen in the Saru River during the major sediment transporting

Fig. 13. Illustration of channel response to landslide debris in the torrential river.

Fig. 14. Illustration of channel response to landslide debris in the placid stream.

events (1961 and 1962). The failure of foot slopes and the extreme bank erosion was found to have occurred during these torrential rains. We found no significant effect from the landslide debris on an adjacent lower reach.

On the other hand, when the fluvial transport could not keep pace with the rate of discharge of the landslide debris from the hillslope, the formation of a large talus could be expected on the toe of a slope (Fig. 13b). This might also cause a constriction of the river channel. This phenomenon could be clearly seen in the landslide of 1966 and even more dramatically during the storm of 1981 in the Saru River.

In the case of a placid stream, as with Jyurokusen Creek, the responses of the channel were characterized by the formation of a pond in the area of the moving hillslope (Fig. 14a) and an abrupt change in the stream bed in the adjacent lower reach (Fig. 14b). This was because the transport ability of stream flow was insufficient to remove the higher rate of sediment produced by landslides.

Most of the landslide debris was transported to the lower reach, and could not be delivered a longer distance as would happen in the case of a torrential river. The significance of the effect of landslides on a channel could still be distinguished. The debris was not readily delivered downstream and stream channel could easily become substantially constricted.

Conclusions

Deep-seated lanslides can produce large quantities of debris since they move with a sliding depth of several meters. These large quantities of sediment are probably produced and transported episodically during major climatic events. On the other hand, shallow debris slides and creep are persistent processes. These two general types of processes cause the change of slope morphology.

Most of the subsequent landslides occurred at the areas of former failures. They would expand by overtopping upslope or reactivating intensively on the same slope plane. Large landslide events and voluminous debris flows frequently occur in a basins and play an important role in supplying sediment into the main channel.

Sediment production discharges by debris slides form flood plains during major climatic events.

The depth and distribution of the deposits in overloaded streams varied in accordance with the width of the stream channel and the transport ability.

References

1) Aipassa, M. and Shimizu, O.: Geomorphic process and natural revegetation on landslide scar in Teshio Experiment Forest, Hokkaido University. Research Bulletin Experiment Forests, Hokkaido University. Vol. 45, 3, 691-716. 1988.

2) Aipassa, M. and Shimizu, O.: Landslide and its effects on channel morphology in forested drainage basin. Proceeding of the International Symposium on Erosion and Volcanic Debris Flow Technology. Yogyakarta-Indonesia S32. 1-9. 1989.

3) Shimizu, O. and Aipassa, M. : Slope changes by landslide and sediment discharge in Teshio Experiment Forest. Technical Report of Experiment Forest College, Faculty of Agriculture, Hokkaido University. pp. 18-19. 1988.

4) Shimokawa, E.: A natural recovery process of vegetation on landslide scars and landslide periodicity in forested drainage basin. Proceeding of Symposium on Effects of Forest Land Use on Erosion and Slope Stability, Honolulu, Hawaii. 1984

要　約

流域においては豪雨時に大量な土砂の生産・輸送が行われるが，土砂生産源として主要な地すべりの型と頻度は場所によって多様である。斜面侵食により生産された大量の土砂は，渓流部に堆積し，土石流発生時に隣接・下流域の河床形態に影響を及ぼす。

本研究は，流域（斜面あるいは河川）における土砂移動を，継時的な航空写真の判読と野外調査データから検討したものである。研究対象流域は沙流川中流域と問寒別川支流の十六線川とした。

(1) 地すべりの型は，母岩の風化様式により大きく規制される傾向がみられ，深層すべり型と浅層流動型は高粘着性の蛇紋岩風化粘土地域に，また浅層崩落型は低粘着性の泥岩風化礫地域に多く分布していた。大規模な深層すべりは豪雨によって数年おきに発生していたが，浅層すべりやクリープは年単位の移動が計測された。

(2) 地すべり地においては，ほとんどの場合地すべりが再移動しやすい状況にあり，同一斜面あるいは隣接斜面で地すべりが繰り返し発生していた。このような地すべり再移動現象は，時間が経つにつれて広がっていく傾向にあり，地下水の集中と地形条件に関係があると考えられた。

(3) 地すべり上部から供給された斜面下部の崩積土は，1966-1981までの15年間に12回の変動（平均1.3 m）を示したが，1981年以降は活発な移動はほとんどない。

(4) 地すべり地は土砂移動や斜面形態の状況から，a)崩壊域，b)土砂流動域，c)堆積域に分けられた。

(5) 地すべり地から生産される土砂の堆積量が河川の浸食量より大きいと斜面下部に大規模な崖錐ができ，一方，浸食量が斜面の堆積量を上回ると崖錐が極度に浸食されて斜面下部で崩壊が生じることが推測された。

(6) 小流域では，地すべりにより生産された多量の土砂はすぐには移動せず，川幅と土砂の輸送能力との関係から河床堆積地の分布を規制していることが考えられた。

Photo 1. Scars formed by successive deep-seated landslides (Saru River).

Photo 2. Large accumulation of landslide debris in the foot slope (Saru River).

Photo 3. Effect of slope movement in the area of the moving hillslope (Jyurokusen Creek).

Photo 4. Effect of slope movement on adjacent channel (Jyurokusen Creek).