Geomorphic Process and Natural Revegetation on Landslide Scars in Teshio Experiment Forest, Hokkaido University

By

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地すべり跡地における斜面変動と植生回復

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Abstract

The past history of large scale mass movement, such as the magnitude and frequency of landslide, was traced by means of dendrochronology. The natural even aged stand existing on the landslide scars provides the chronological information for the past geomorphic process. Dendrochronological study is applicable to the dating of the past landslide.

The immense variety of slope surface form observable in the field is regarded as due to the transport process which operates in varying combination according to the characteristics of slope materials. The traces of the large scale mass movement were not easily discernible since it occurred in the old times. However, the recent geomorphic process, which was found to be small of scale is relatively easier to recognize by their configurations under the present climatic and geomorphological condition since these configurations were not effaced by rainwash or others.

The failure of natural revegetation on both investigated landslide scars is most likely due to the unstable ground condition on which seeds of plant were unable to germinate properly. The unstable ground conditions are assumed to be due to the presence of surface flows, active soil movement and movable coarser slope materials.

Key Words: Dendrochronology, Landslide scar, Geomorphic process, Serpentine, Mudstone.

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Contents

Introduction

It is nothing of common if Japan is frequently called as the country of disaster as can be seen in the historical report of disaster. Every year Japan experiences natural disasters caused by mass movement as debris flow or landslide that threaten lives and properties particularly in the densely populated areas. This may seem to be related to the geophysical condition of Japan which chiefly consist of mountainous area (73%) having steep topography, their major topography covers a large area. Thus the mountains owe their topography to mass movement. In addition to this condition, the sediment disasters seem to be related to climatic condition since Japan is situated in a region of heavy rainfall where the continental air current merges with the oceanic air current in its vicinity. Moreover, the land of Japan is frequently hit by typhoons.

Landslide is a part of geomorphic process which have a variety of negative effects on natural resources and property. These impacts include on-site damages to standing timber, and roads, and off-site impacts such as increasing sediment production on river, degradation of water quality, and damages to aquatic habitat. Landslide is caused by instability of slopes and may involve displacement of large volumes of earth materials.

In the planning of landslide prevention works, it is important to recognize the past hillslope failures and the recent condition of landslide scars in various geological structures.

The purposes of this study are to discuss the slope surface forms which are related to the characteristics of slope materials on the landslide scars, to trace the past history of the geomorphic process with special reference to dendrochronology, and moreover, to know the natural revegetation on landslide scars. For these purposes, serpentine and mudstone areas in the northen part of Hokkaido were chosen as study areas.

I. Study method

1. Method

The recognition of investigated landslides was based on the interpretation of aerophotographs and the field investigation. The aerophotographs taken by Teshio Experiment Forest of Hokkaido University in 1977 were used to recognize the landslide sites. Besides using the aerophotographs, forest type map showing the distribution of landslides, contour lines, and small catchment areas was also used. Generally, the required landslide sites could not be fully recognized, and so field investigation on those sites including the

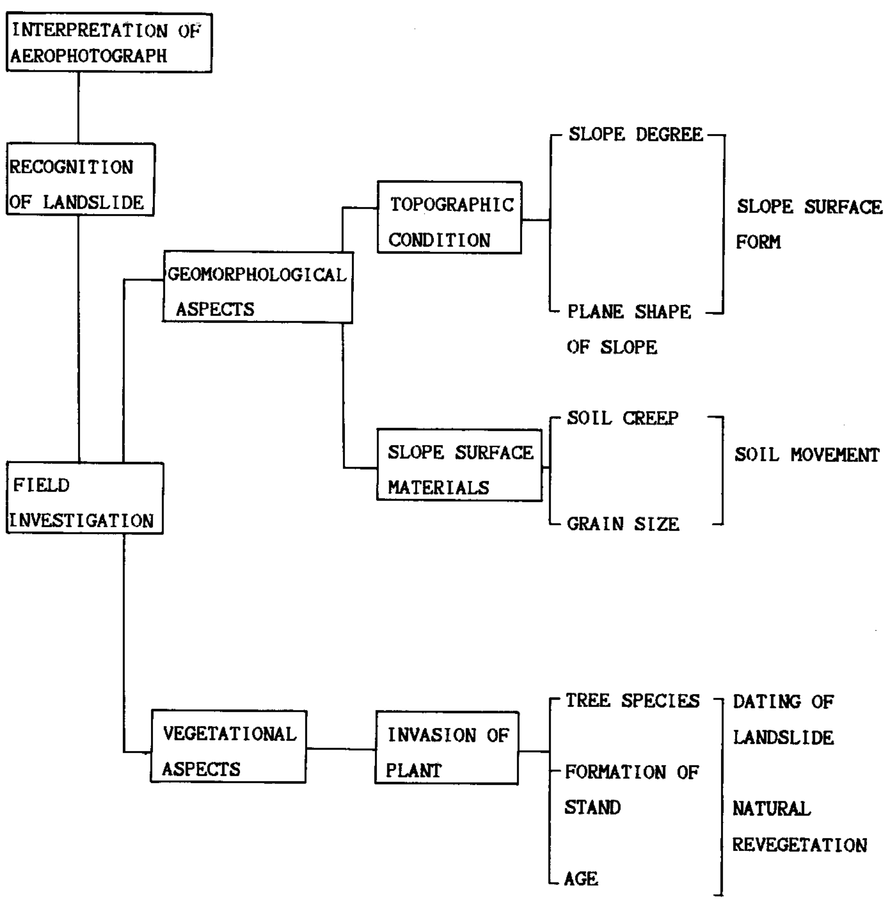

Fig. 1. Study method.

geomorphology condition such as the rupture of slope, main scarp, cliff, longitudinal slope surface form, deposited slope debris etc., and vegetational condition including the formation of natural revegetation, the curvature of trunk etc. was undertaken (Fig. 1).

Geomorphological investigation consists mainly of two works, namely the observation of topographical characteristics and the analysis of the nature of soil movement. In order to recognize slope surface forms, the measurement of microtopography, involving the degree of slopes, and the plane shape of slope including the length and width of slopes, was carried out. Besides the characteristics of topographical condition, the slope surface materials were also analyzed. Other elements observed in the analysis of soil movement were soil creep measurement and the analysis of grain size distribution of slope materials. The soil creep measurement was only applied in serpentine area and was used in the examination of the slope degree and the water content in soil. Since the soil consists mostly of coarse particles which is somewhat deep, pegs for measuring soil creep could not be firmly embedded consequently no soil creep measurement was performed in the investigated site of mudstone area.

Vegetational investigation was carried out to know the natural recovery of landslide scars. Those vegetational characteristics were also used in clarifying the geomorphological process, such as magnitude, and frequency of landslide. Dendrochronological method including the analysis of annual rings of tree, the abnormal growth of tree, and the formation of natural vegetation was used to achieve those purposes. This method actually has been applied by ARAYA (1986). The effectiveness of this method has been proved in various parts of Hokkaido, particularly in the study of the changes of topography caused by landslide (HIGASHI, 1979).

2. Study areas

Geographically, the study areas are located on the line of 45° north latitude, and belong to the Teshio Experiment Forest of Hokkaido University (Fig. 2). Based on the geological structure, the study areas consist of two parts separated by the Toikanbetsu River which is the tributary of the Teshio River. The east side is composed of serpentine, which was probably formed at the end of Mesozoic era, while the west side is almost composed of mudstone and sandy mudstone which belong to the fold zone in Neogene system of Tertiary era (MATSUI, 1963). Accordingly, two different vegetations appear corresponding to the two geological structures.

In the serpentine zone, pure forest of *Picea glehnii* is distributed with some special floral communities. In mudstone zone, mixed forest of coniferous and broadleaved trees, such as *Abies sachalinensis, Picea jezoensis, Quercus mongolica* var. grosseserrata, *Kalopanax pictus, Ulmus davidiana, Betula ermanii, B. maximowicziana* etc. are widely distributed. The forest floor is densely covered with *Sasa kurilensis* or/and *Sasa senanensis*. Historically, forest fire had occasionally occurred since 1910, by which the cumulative area of damaged forests amounted totally to 11,500 hectares and the burnt forests amounted to 6,000 hectares. In the burnt land, secondary forests are partially growing but treeless land also widely remains (EXPERIMENT FOREST of HOKKAIDO UNIVERSITY, 1986).

Figures 3 and 4 show the maps of the investigated landslide in serpentine and mudstone areas. The Mukaihassen River flows from the east side of the Teshio Experiment Forest passing a numerous landslide sites of various dimensions and finally ends in the

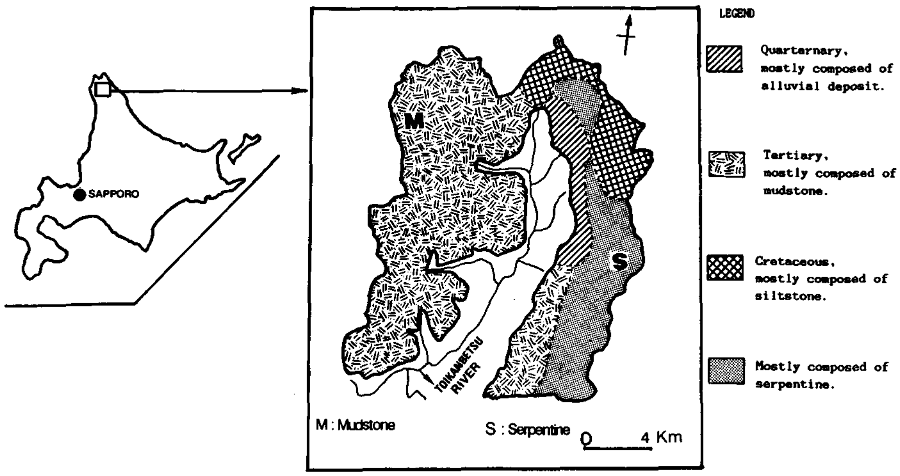

Fig. 2. Locations of the investigated areas (M. S).

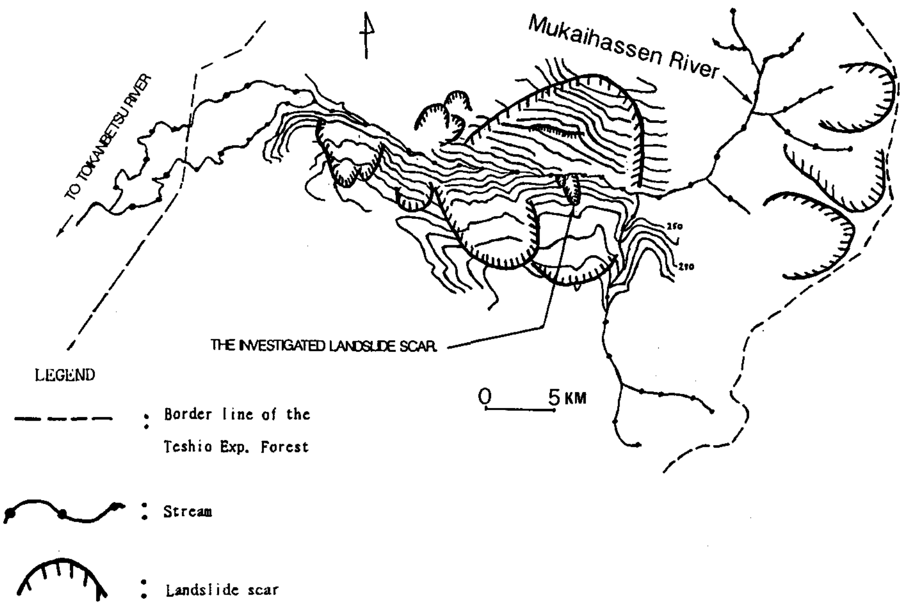

Fig. 3. Map of the investigated landslide scar in the serpentine area (S).

Toikanbetsu River. The right side of this river is largely covered by grassland and shrub, and most likely these are remains of burnt forest. Unlike in the Mukaihassen River, Jyurokusen River landslide sites are confined in number and are small in scale. This placid river flows from the west side of Teshio Experiment Forest to the east side and ends in the Toikanbetsu River.

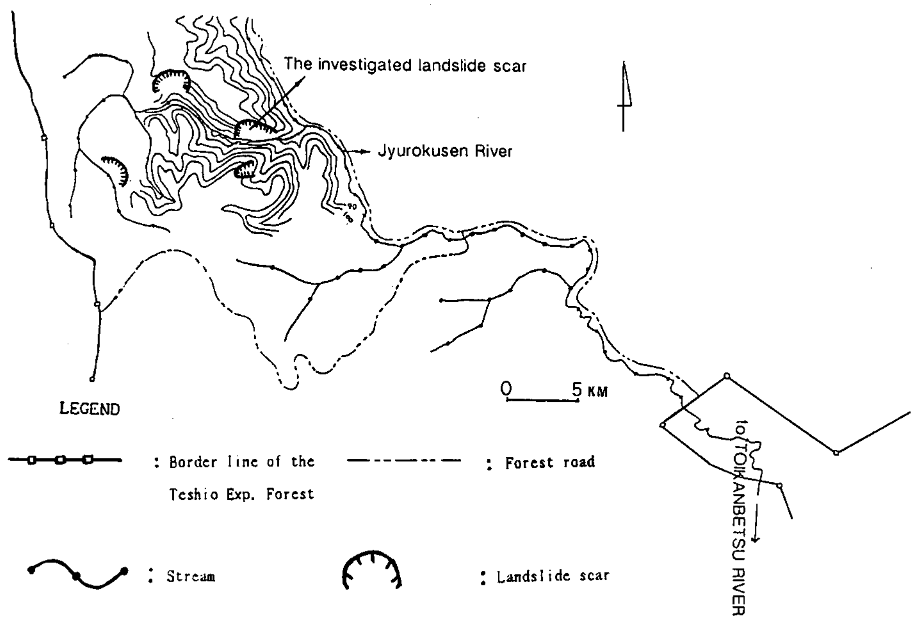

Fig. 4. Map of the investigated landslide scar in the mudstone area (M).

II. Topographical and vegetational condition of the landslide scars

1. Topographical condition

Figure 5 shows the longitudinal profile of landslide scar investigated in serpentine area. Generally, the slope degree is more gentle than that landslide investigated in mudstone area. The mean slope degree is 21°. The extensive length of landslide scar slope was found to be around 190 meters and is composed of complex slope forms, such as concave, convex, and rectilinear forms. Besides these forms, cliff was found situated among them. The total dimension area of landslide is estimated to be approximately 14,000 m^2.

Figure 6 shows the longitudinal profile of the landslide scar investigated in mudstone area. The total dimension area of landslide scar is smaller than that in serpentine area. It is estimated to be approximately 5,500m^2 while the horizontal distance is estimated to be about 70 meters and exhibits steeper slope (38°) than that in serpentine area. The longitudinal profile is mostly rectilinear.

2. Vegetational condition

Vertical view of landslide scar investigated in serpentine area (Fig. 7) shows the distribution of invaded trees. The middle part to the summit of slope is densely covered by vegetation, while the downward part is almost bare on which small gullies develop from the summit of baren slope channeling to the stream. Based on the vegetational investigation carried out on the vegetated site of landslide scar, the composition of forest mostly consists of natural even-aged stand of *Betula ermanii*. This is the single dominant plant species and is mostly distributed and laterally expanded on the relatively gentle slope.

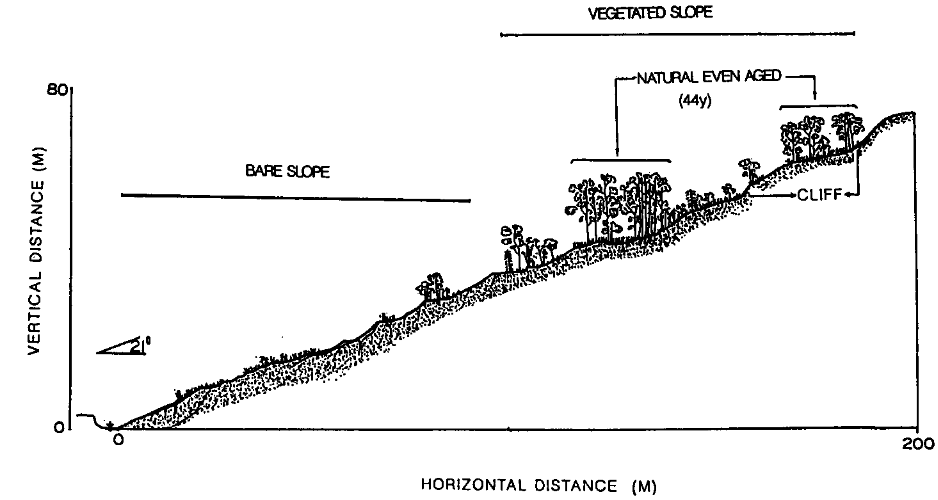

Fig. 5. Longitudinal profile of the landslide scar, investigated in the serpentine area.

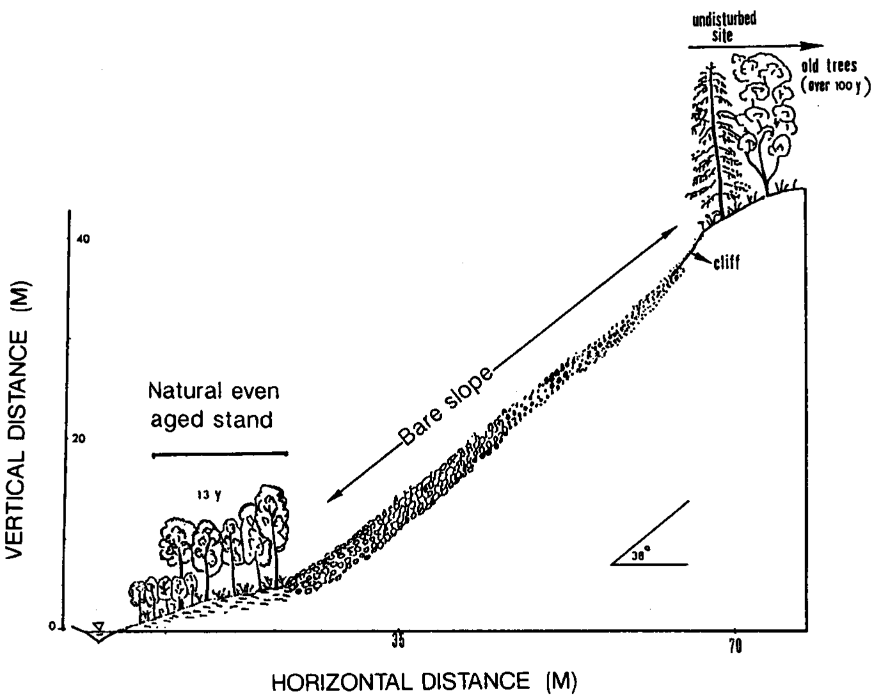

Fig. 6. Longitudinal profile of the landslide scar, investigated in the mudstone area.

Table 1. Invaded trees on landslide scar, taken within 20m×5m size of plot in the serpentine area (S)

Species	Number	Average		Age
		Dbh (cm)	Height (m)	(y)
*Betula ermanii**	9	13.3	14.6	44
		13-15**	15-16**	
Salix sp.	2	10.9	8.2	
Sorbus sp.	1	3.9	4.4	
Hydrangea sp.	1	3.6	3.2	
Total number	13			

Note: * Dominant tree (age: 44, derived from 2 trees).
** Range, obtained from 6 trees.

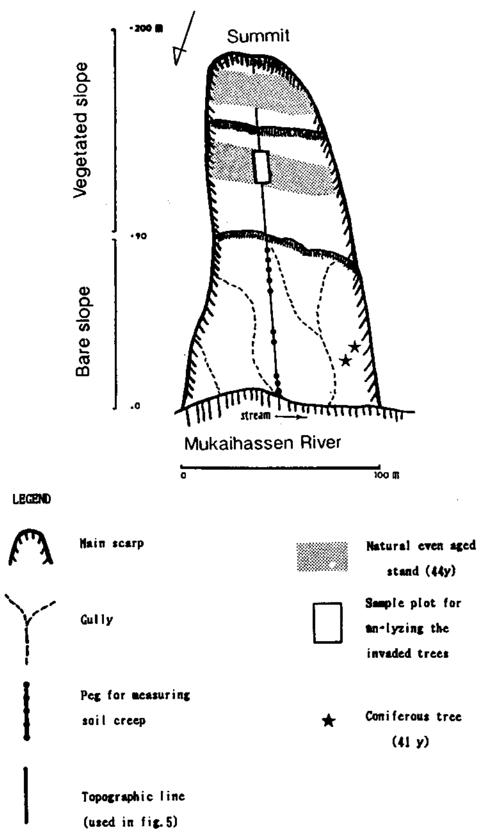

Fig. 7. Vertical view of the landslide scar, investigated in the serpentine area.

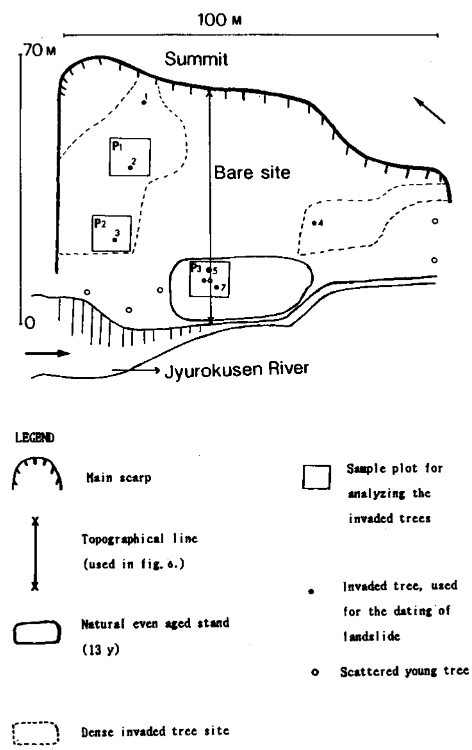

Fig. 8. Vertical view of the landslide scar, investigated in the mudstone area.

Table 2. Invaded trees on landslide scar slope, taken within 10m×10m size of plot (P1)* in the mudstone area (M)

Species	Number	Average		Age
		Dbh (cm)	Height (m)	(y)
*Betula ermanii***	4	5.4	5.0	19
*Salix sp.***	10	6.0	5.4	
*Prunus sp.***	5	4.9	6.0	
*Picea sp.***	7	6.5	5.3	
Abies sp.	1	3.3	2.3	
Quercus sp.	1	6.9	4.0	
Sorbus sp.	1	4.4	4.0	
Total number	30			

Note: * The position of sample plot (P1) is presented in Fig. 8.
** Dominant trees species. The range of dbh, and height are 4.3-7.3cm and 4.2-6.9m, respectively (obtained from 14 trees).

Table 3. Invaded trees on landslide scar slope, taken within 10m×10m size of plot (P2)* in the mudstone area (M)

Species	Number	Average		Age
		Dbh (cm)	Height (m)	(y)
*Betula ermanii***	15	5.2	5.4	21
*Salix sp.***	14	5.2	5.1	
Sorbus sp.	8	3.8	4.1	
Picea sp.	8	3.3	2.9	
Betula sp.	5	3.0	3.5	
Abies sp.	1	3.0	2.6	
Ulmus sp.	1	1.6	2.0	
Total number	52			

Note: * The position of sample plot (P2) is presented in Fig. 8.
** Dominant trees species. The range of dbh, and height are 5.0-8.8cm, and 4.0-8.5m, respectively (obtained from 14 trees).

The average age is estimated to be about 44 years old. The result of vegetational investigation is shown in Table 1.

Figure 8 shows the distribution of invaded trees on the landslide scar, investigated in mudstone area. The distribution is not uniform. It is concentrated in the lower part of landslide scar slope up to the summit, which is bare in the centre part of the slope. The invaded trees growing on the landslide scar slope is shown in Tables 2 and 3. Deposited slope debris is formed in the downslope site and they partially blocked the stream on which natural even-aged *Salix sp.* was found. The number, diameter, height, average age of invaded tree is listed in Table 4. Some invaded trees on landslide scar were taken for the analysis of annual rings. The list is presented in Table 5.

Table 4. Invaded trees on deposited slope debris site, taken within 10m×10m size of plot (P3)* in the mudstone area (M)

Species	Number	Range of dbh (cm)	Range of height (m)
*Salix sp.***	2	13.0-14.0	8.0-12.0
	8	9.0-11.5	
	4	4.0- 7.0	4.0- 7.5
	4***		
Alnus sp.	5	6.5- 9.0	7.0-10.0
Total number	23		

Note: * The position of sample plot (P3) is presented in Fig. 8.
** Forming an uniform stand (13 years old).
*** The trunk is broken.

Table 5. List of sample trees, used for the dating of landslide in the mudstone area (M)

Code no.	Species	Dbh (cm)	Height (m)	Age (y)	Position
1.	*Betula ermanii*	3.0	3.5	20	on sloping site
2.	*Betula maximowicziana*	6.0	5.2	19	〃
3.	*Betula sp.*	6.0	6.5	21	〃
4.	*Salix sp.*	9.5	8.5	21	〃
5.	*Salix sp.*	11.0	11.6	13	on deposited slope debris site
6.	*Salix sp.*	9.0	12.0	13	〃
7.	*Alnus sp.*	6.5	9.8	12	〃

Note: The position of sample trees is presented in Fig. 8 (marked by code number).

III. Movement of slope surface materials

1. Slope surface form

This geomorphic process is regarded as subsequent process occurred after the large scale mass movement (: landslide). Process is classified as a small scale and slow mass mevement. It is relatively easier to recognize by their configuration under the present day climatic and geomorphological conditions. The movement of slope materials are presumed to be generally still active since the surface slope forms produced by mass movement are expressive, being not effaced by rainwash or other agents. The immense variety of slope surface form observable in the field is regarded to be due to the transport prócess which operates in varying combination according to the characteristics of slope materials. Certainly, the problems cannot be fully and precisely solved by only considering those factors since there are so many factors affecting the slope form and its process. Moreover, those factors usually acts simultaneously.

The determination of slope surface form was carried out based on the recent forms which appeared from the longitudinal profile. The longitudinal profile was obtained by the measurement of microtopography which involved the slope length and the slope degree. The varying forms of slope surface (concave, rectilinear, and convex forms), was roughly determined by dividing each form into several sections according to their distribution along the whole longitudinal profile of slope. The length of each sections were determined to be approximately 20 meters to 30 meters based on the fact that most of the slope forms are distributed in those relative lengths. The longitudinal profile of slopes obtained from the microtopographical survey are redrawn in a proper scale in order to provide the determination of slope surface form accurately.

a. Complex slope form

In the case of slope form in serpentine area, complex form of slope was found. This was assumed to be formed as a result of rainwash and deposition processes which take place alternately over the extensive length of the relatively gentle slope. Generally, there were three groups of slope forms observed.

Firstly, concave slope which is presumed to be formed where rainwash effectively takes place particularly on the steeper part of slope. The slope material in this part of the slope was transported downward from the crest and finally resulted the wanning development (concavity section). It is theoretically possible to envisage rainwash as an important formative process on the steeper part of slope, particularly near, and at the summit of slope. This was also found in mudstone area, although the section of concavity is not as extensive as that in serpentine area. This process was also found at the lower part of slope, where surface flow had increased to the extent that small scale channels could occur. This concavity was found to be a dominant form (44.8%) of the total length of slope in serpentine area. SMALL (1979) proposed that in the lower part, slope will commonly exhibit a concave section. In some cases this concavity will result from depositional process.

Secondly, convex slope which is assumed to be formed mainly by the accumulation of transported materials. These materials are deposited on the gentle part of the slope and they finally lead to a gradual waxing development (convexity section). This section is ordinarily found on the absence of effective wash, so soil creep activity is usually and on the contrary highly developed in some convexity sections of slope. This form was found to be a minor slope form (15.5%).

Thirdly, rectilinear slope. Most of the rectilinear section was found on the steeper part of downslope and it was restricted to the central part of slope profile, where it separates a convexity above from a concave below. This section may reflect a condition of approximate balance between the downslope increment of load and the downslope increment of efficiency of slope transportation. This slope form was also found to be as extensive (39.7%) as concavity section.

b. Simple slope form

The case of slope form found in mudstone area is somewhat different from what was found in serpentine area, where marked rectilinear (or straight in profile) section dominated at about 77.5% of the total length of slope, while convex slope, that is mainly formed by the deposition of the slope materials from the upper part of slope, occupied the downslope site forming a talus slope. However, this section is confined only in the downslope site. This rectilinear section is related to the slope material characteristics.

The coarse and consolidated particles are assumed to be the strong factor promoting the rectilinear slope form. The concavity, and convexity sections are conversely displayed at minimum since the downslope transportation of slope materials becomes more increased and so the slope load is moved downward straight without making any concave and/or convex slope profiles through the gravitational force. The proportion of slope profiles observed in the investigated sites is presented in Fig. 9.

2. Landslide soil characteristics

In this study, soil movement on slope is simply described according to their soil characteristics. No detailed laboratory analysis of the physical properties of landslide soil was conducted. However, visual impression of the field observation was carried out to understand the characteristics of slope material movement in general. In order to understand the characteristics of soil movement, the available data of soil plasticity characteristics of serpentine area and mudstone area, carried out by ARAYA and MURAI (1966) in Nakagawa District, which is located near the investigated areas, were used. This approach is based on the reasonable assumption that those soil characteristics have similarities to the soil characteristics in the investigated areas. The Casagrande Plasticity Chart was used in classifying soil plasticity group, from which the general nature of soil may be obtained.

The slope materials of the landslide scar investigated in serpentine area were known to be mostly composed of fine material and somewhat impermeable. Based on the Atterberg Limits shown in Table 6, in serpentine area, plastic limit and both plasticity index and its range show high value. According to the Casagrande Plasticity Chart (Fig. 10), this soil is classified into an inorganic clays of high plasticity. This may indicate the increase of the bounding properties of fine clay and colloidal fraction of material. Accordingly, it may have high consolidation characteristics under stress (KAROL, 1960).

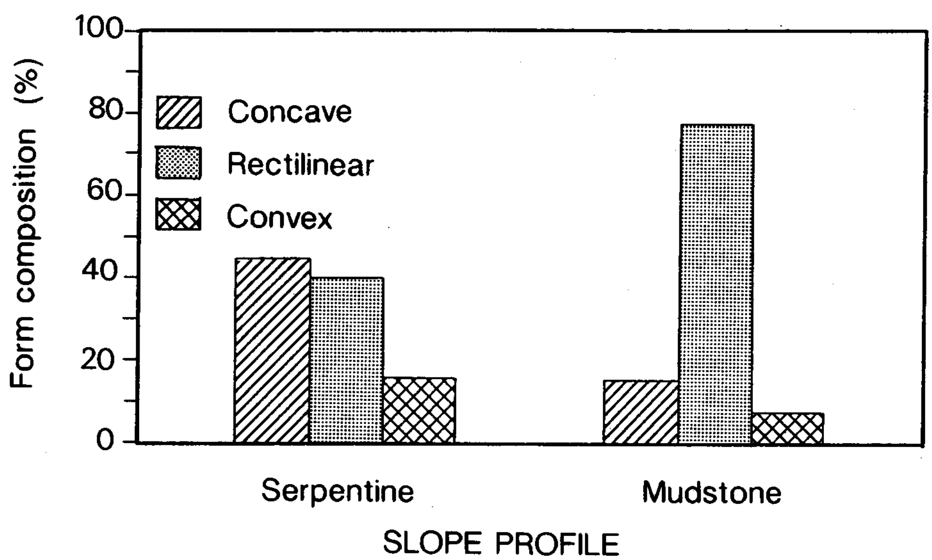

Fig. 9. Slope forms of the investigated landslide scars.

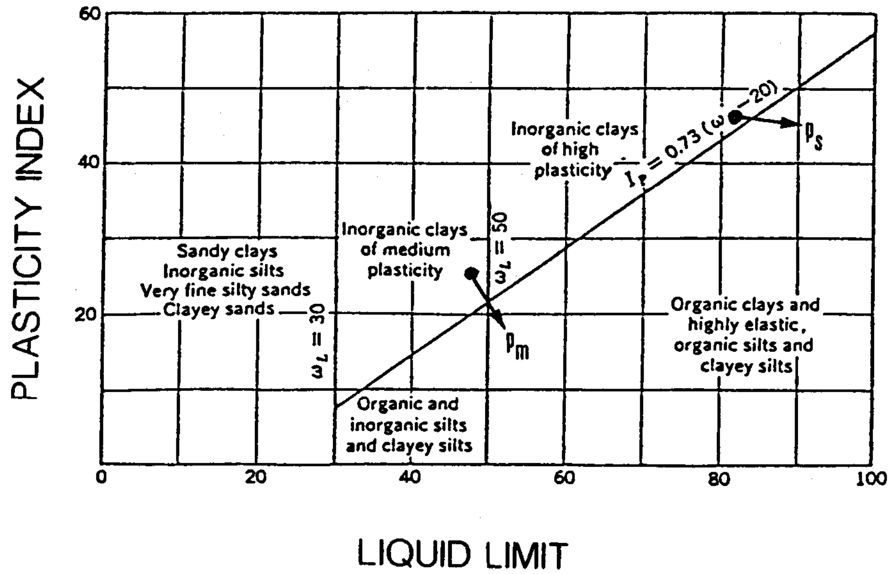

Fig. 10. Casagrande Plasticity Chart (after CASAGRANDE, 1948).
Ps and Pm are referred to the soil plasticity group, investigated in the serpentine and mudstone areas.

Through the rough observation in the field and based on the characteristics of the soil itself, the slope materials observed in serpentine area is assumed to be moved down mainly in the form of a small block of slide plane. The high cohesiveness of clay and the impermeability of soil seem to play a main role in this movement type. This characteristics could be clearly seen in the field by observing the ground surface which is initiated with the evidence of crack and creep before moving downward.

Unlike in the case of slope material characteristics observed in the investigated site of

Table 6. The Atterberg Limits of the landslide soil of serpentine and mudstone areas, carried out in the Nakagawa District (after ARAYA and MURAI, 1966)

	Site	Samples	Mean (%)	Estimated range (%)
Liquid limit	serpentine	18	80.7	66.6-94.8
	mudstone	17	49.2	42.0-56.4
Plastic limit	serpentine	18	36.7	32.0-41.4
	mudstone	17	23.5	21.4-25.6
Plasticity index	serpentine	18	44.0	33.3-54.7
	mudstone	17	25.7	18.3-33.1
Flow index	serpentine	18	49.8	35.5-64.1
	mudstone	17	9.0	7.8-10.2

serpentine area, slope materials in mudstone area are mostly composed of coarse materials and are unconsolidated. Based on the Atterberg Limits in Table 6, the plastic limit index and its range show low values. According to the Casagrande Plasticity Chart this soil in classified into an inorganic clay of medium plasticity, having increasingly poorer compaction characteristics and low densities (KAROL, 1960). Based on these characteristics and also on the field observation, the slope material in this investigated site is presumed to be abruptly moved downslope mainly in the form of separate grains after getting stress. The slope material seems to be easier transported downslope not only by external factors but even by the weight of their own particles which have less cohesiveness and seem to be friable.

3. Grain size distribution of slope material

Since the weathered slope materials consist mostly of deep granular particles, peg for measuring the soil creep could not be firmly embedded. Consequently, no soil creep measurement was carried out in the investigated landslide scar of mudstone area. However, the analysis of grain size distribution of slope materials was examined merely to understand the soil action on the slope. The length of slope was systematically divided into three parts, such as upper part, middle part, and lower part, respectively. The soil samples were taken on each part. Subsequently, grain size of slope materials was analyzed and classified into several sizes according to the JIS (Japan Industrial Standard).

Table 7. Percent weight of slope materials, examined in the landslide scar of the mudstone area (M)

Size of	Position on slope		
particle	Upper part	Middle part	Lower part
> 20mm	—	6.2	26.9
10—20mm	13.7	19.7	41.6
2—10mm	48.0	45.4	24.9
0.84— 2mm	11.0	8.0	1.7
<0.84mm	27.3	20.7	4.9

Most of the size of the material varied from 2 to 20 mm. The percent weight of the slope material of the investigated landslide scar in mudstone area is presented in Table 7.

In the upper part of slope, materials were mainly composed of finer materials. This part is mostly dominated by the materials with sizes varying from 2-10 mm (occupy 48.8%), followed by the materials with sizes less than 2 mm. The coarser materials (10-20 mm) still exist even if it is confined in amount (13.7%). Materials with sizes bigger than 20 mm were not found entirely in this part. In the middle part of slope, composition of grain size tend to change. The percentage of finer materials begins to decrease even if they still dominate as it was found in the upper part of slope, while the materials with sizes bigger than 20 mm and with sizes between 10-20 mm begin to occupy this part of slope. However, the percentage is still small, about 6.2% and 19.7%, respectively. According to these percentages, it can be said that this part is the transition site of grain size change. The trend could be clearly seen in Fig. 15. In the upper part of slope, the coarser materials, especially those materials with size between 10-20 mm occupy as the dominant material, with a high percentage (41.6%), followed by materials bigger than 20 mm (26.9%). The percentage for finer materials decreased.

Based on the tendencies seen above and in term of transport potential it can be stated that the coarser the material is, the more distant the materials are pushed downward from the summit of slope. On the contrary, the finer materials tend to move downward with relatively slight transport potential. The action of those materials is presumed to be affected by the gravitational force as it is found in the most natural phenomena. The slope material characteristics inevitably is a condition favoring the transport process. The coarser materials detached from the upper part were firstly accumulated on the downslope site (as a dominant particle) because of the monentum they gain during the sliding movement. The finer material which moved down at a lower velocity is retained by the coarser material and finally formed a talus form. The characteristics of soil action mentioned above may reflect the type of slope material movement itself on slope. The materials seem to be moved downward in a form of separate grain as favored by gravitational force.

4. Soil creep

In order to understand the characteristics of soil movement on landslide scar, soil creep activity was analyzed. Soil creep measurement was only conducted in serpentine area and was examined with respect to the slope degree and the amount of water. Those factors constitute the agencies affecting the rate of soil creep (SHARPE, 1938; and TERZAGHI, 1950). Soil creep measurement was performed by knocking small pegs into the soil and measuring their displacement with reference to a marker embedded in the slope surfaces. Pegs are systematically plotted on three sites of slope, namely the lower part, middle part, and upper part, respectively. In each part of the slope, several measurement points of soil creep were performed over a certain length, from which the soil creep of each part is counted. The slope surface gradient of each part were also measured to understand the effect of slope degree to the soil creep. In addition, the water content of soil was also measured so as to know their effect. Unfortunately this later measurement was only carried out in the final measurement of soil creep. Consequently, the result is not fully representative of the whole duration of measurement since the value of water content may vary according to the period of season.

The soil creep was found to vary according to the steepness of slope. In a slope of

Table 8. Soil creep on bare slope, measured within a year (October 1986—October 1987) in the serpentine area (S)

Position on slope	Slope degree (°)	Length* (cm)	Soil creep (cm)
Lower part	25	452.1	63.2
Middle part	9	354.6	5.0
Upper part	22	447.2	20.1

Note: * Mean slope length on which soil creep is measured.

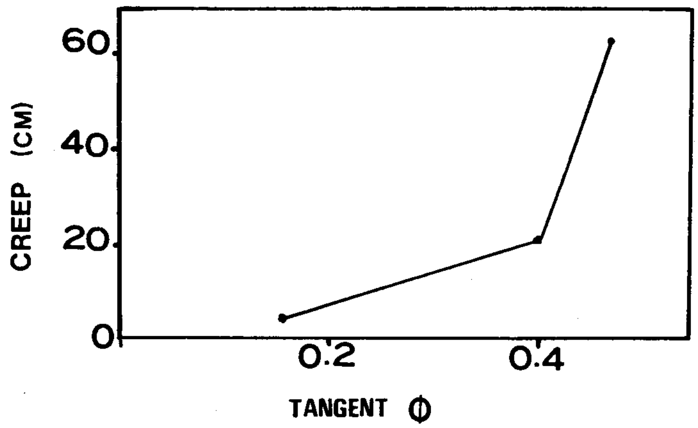

Fig. 11. Correlation of soil creep and slope degree, examined in the serpentine area.

more than 22°, soil creep was found to be 20.1 cm to 63.2 cm within a year, and in a slope of around 9°, soil creep was found to be about 5 cm (see Table 8). These values reflect the considerable high potential of slope material movement which is presumed to be due to the factors of slope steepness and water content of soil. SCHULTS and CLEAVES (1955) stated that creep may be caused by a great number of agencies such as the type of material, its physical condition, angle of slope, climate, and vegetation cover. Soil creep tends to vary directly with slope degree (Fig. 11). The steeper the slope degree is, the higher is the magnitude of soil creep. Conversely, the decrease of the magnitude of soil creep is proportional to the decrease of the slope degree. In this phenomena, gravitational force seems to be a factor responsible for the creep. PENCK (1953) proposed that as the slopes

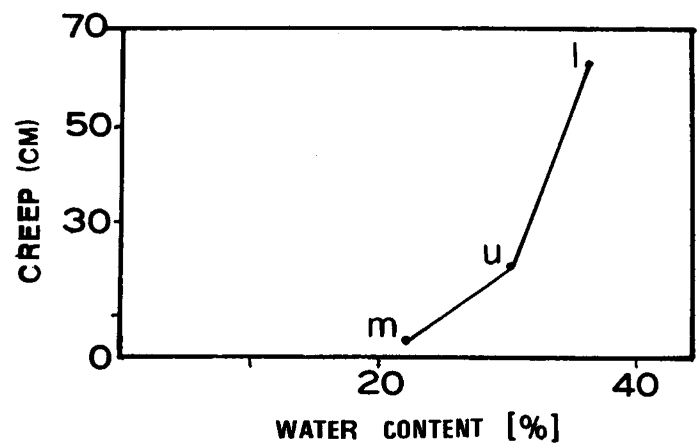

Fig. 12. Trend of soil creep toward the water content of soil, examined in the serpentine area. Each point indicates the position of the measured creep on slope (m : middle part, u : upper part, and l : lower part).

become progressively steeper instability of soil cover becomes marked. In the middle part of slope, the soil creep is at minimum since the slope degree is relatively low. Moreover, that part is partially covered by vegetation including grasses that is undoubtedly a very important influence on the rate of creep. In the lower part on which the slope is steeper, soil creep is at maximum while on the upper part it was found to be smaller. However, it is odd that field observations by SCHUMM (1956) revealed that erosion by creep (removal of soil surface) can be greatest at or near the crest of the slope and less at the base despite the steeper angle there.

As in the case of slope degree, the magnitude of soil creep also tend to increase with the increase of the amount of water on soil. The higher is the amount of water, the more rapid is the slope surface material moved downward. The trend of the amount of water on soil to the soil creep is presented in Fig. 12. The presence of water is important not only for its lubricating effects, but also because it causes certain clay minerals to swell and move adjacent particles. Water action is intermittent, and is really effective only during and after prolonged or heavy rainfall or when thawing of a snow cover takes place (SMALL, 1970).

IV. Natural recovery of landslide scars

1. Invasion of pioneer trees

The natural forests in serpentine area consist of pure forest of *Picea glehnii* distributed along with some special floral communities. In a certain interval after landsliding, however, the composition of forest in landslide scar itself had extensively changed into pioneer tree vegetation. Most likely those pioneer trees began to invade landslide scar years after landsliding. Based on the condition of natural revegetation, landslide scar slope in this area can roughly be classified into two groups. First, the dense vegetated slope site situated on the upper part of slope and second, the bare slope situated on the lower part. The area of each distribution is almost equal (Fig. 7).

Through the longitudinal profile measured on the landslide scar at the vegetated slope site, there are at least two forms of terraced plane (Fig. 5) which exhibits gentle slope. On these sites invaded trees densely occupied and tend to form a uniformity of height, diameter and age which is usually termed as natural even-aged stand. The distribution of the natural even-aged is not uniform on the whole slope but it is concentrated in a contour belt. The composition is dominated by *Betula ermanii* (44y) which shows high value either in diameter or height toward the other invaded trees, while *Sasa spp.* (about 2 m in height) was also densely found in the vegetated slope as the forest floor plant. The distribution of invaded trees seems to expand from the dense vegetated site to surrounding sites gradually as time passes by. The distribution of those pioneer trees is most likely promoted by the favorable land surface. A number of the seeds of anemophilous plant might reach the bare slope after landsliding on the relatively gentle slope, where the erosional forces seem to be not active, they were successful in the germination process. Besides *Betula ermanii* and other broadleaved trees, *Picea sp.* were also found in the vegetated slope site. However, they were limited in number although the surrounding mother trees are mostly consist of *Picea sp.* Perhaps, they were unable to compete in taking nutrient, light, and living space, just after landsliding when they began to invade together with those pioneer plants and undergrowth on the exposed site.

Unlike the drastic change of forest composition which occurred in the serpentine area after landsliding, the pioneer plants in the mudstone area which invaded a part of landslide scar slope, were generally derived from the surrounding mother trees. Broadleaved trees as *Betula ermanii, Salix sp., Sorbus sp., Ulmus sp.,* and coniferous plants as *Picea sp.* and *Abies sp.* were found living together as invaded trees. Besides these trees, *Sasa spp.* also densely covered a part of the landslide scar site. The invaded trees were not uniformly distributed in the whole landslide scar site but were distributed in a mozaic form. At least, there were two groups of invaded trees distribution, those groups located on landslide scar slope and those groups located on the deposited slope debris site situated in the lowest part of slope borders on the stream.

Chronologically, the pioneer trees started invading about 21 years ago, even on the landslide scar site of very steep slopes. However, they tend to be slow in growth. The number of invaded trees ranges from less than 10 to 52 in $100m^2$. This reflect the pursuing disturbances after landsliding. The trees grow slower on the upper part of the slope most likely due to the active rainwash that is shown by the concave slope formed near the summit of slope. Conversely, they grow more properly in the lower part of landslide scar slope which mainly consists of the deposited materials from above, presumed to be the site which is relatively free from active wash. About 8 years after the time of plant invasion on the landslide scar slope, trees also invaded the lowest part of landslide scar slope which is composed of slope debris material forming a relatively flat plane. Based on the vegetational analysis on that site, the invaded trees mostly consist of *Salix sp.* (see Table 4) and the trees form an even-aged stand. Trees show rapid growth; both their diameter and height excel those invaded trees on the landslide scar slope even if they are younger. No soil physical properties analyses were carried out on this site. However, according to the rough obeservation, the condition of land surface seem to be relatively more suitable for seed germination process and also for the subsequent growth of the invaded trees than that of the sloping site on landslide scar.

2. Failure of natural revegetation

Based on the vegetational observation carried out in both the investigated sites, the landslide scar sites were not fully covered with the invaded trees. Baren sites still remain partially on sloping sites. The failure of natural revegetation on both investigated landslide scar sites is most likely due to the unstable ground condition on which seeds of plant were unable to germinate properly. In serpentine area, the unstable ground condition is presumed to be due to the presence of surface flows which may facilitate erosive forces. In addition, soil creep was also found to be extensive as reflected by the appearance of the inclined bend of trunks observable in the lower part of landslide scar. However, young invaded broadleaved trees were found growing sparsely along with *Miscanthus spp.* (grass). Besides these trees, *Picea glehnii*, and *Abies sachalinensis* were found. However they were very few. One of these coniferous trees (41y), which was presumed to be the oldest tree was used as an effective indicator plant related to the time when trees initially invaded that baren site. In mudstone area, the unstable ground condition is presumed to be due to the recurrence of landslide. The soil mantle was mostly composed of coarser material which may result in the instability of land surfaces. Thus, the movable coarser surface materials existing on the slope is most likely the factor leading to the failure of natural revegetation, where in seeds of plant are presumed unable to germinate. Likewise those surviving seedling probably could not stand firmly and thus they were unable to grow properly.

V. Estimation of the past landsliding

1. Type of landslide

Based on the configuration of their recent geomorphic appearances, the type of ancient mass movement in serpentine area is regarded to be "slump". The mass rotates backward so that the slope of the upper surface of the block is diminished or reversed, while the displaced materials form a series of block which slipped down along parallel slip surfaces to the downslope. Slump is known to be the most common type in Hokkaido (CIVIL ENGINEERING ASSOCIATION OF HOKKAIDO, 1985). The landslide investigated in this area showed a main scarp of about 70 meters width, and nearly 200 meters length with a vertical distance of approximately 80 meters.

In the case of large scale mass movement observed in mudstone area, the type is regarded to be as "debris slide". The mass did not slip down by sliding plane, instead it seemed to be moved like some kind of surface failure. In the site near the summit of the slope, the materials were detached so extensively that bedrock was exposed and this led to the formation of small cliff. The rate of this mass movement type can range from feet per year to feet per second depending on the hillslope gradient, the water content, and the existence of special condition, such as the presence of a lubricating cushion of compressed air (DUNNE and LEOPOLD, 1978).

The illustration of slump and debris slide proposed by VARNES (1958) are presented in Fig. 13 in order to provide the clearer type of landslide.

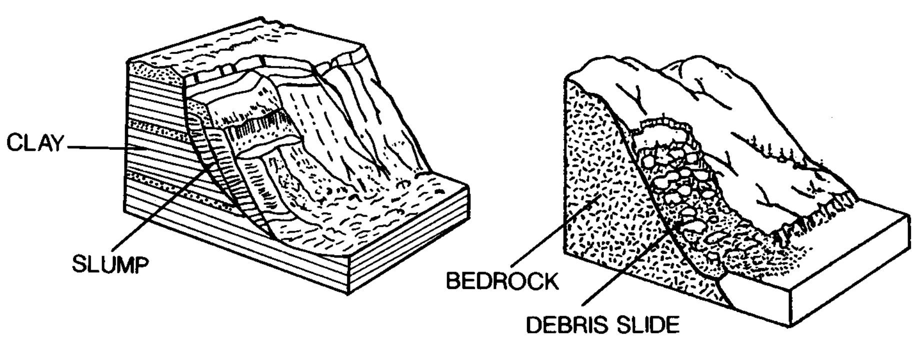

Fig. 13. Types of slope failure (after VARNES, 1958).

2. Magnitude and frequency of landslide

Based on the analysis of growth ring recorded in the invaded trees, the time of landsliding in serpentine area was estimated to be 1944 or several years earlier, with an estimated magnitude of about 14,000m². The age of about half of this value was clearly recognized by using plant indicators, situated on the upper site of landslide scar in which the uniform and concentrated distribution invaded trees can obviously be seen. Plant indicator was not successfully obtained for the lower part of landslide scar slope which was almost bare. However, *Picea spp.*, which is presumed to be the oldest invaded tree on that site, shows an almost equal time of landsliding as that of the upper site.

Based on the historical records of Nakagawa district (NAKAGAWA TOWN OFFICE, 1975), which is situated about 20 km from the investigated area, heavy rainfall, which caused considerable damages, occurred in 1939 and was repeated in 1943. Probably this destructive heavy rainfall has a close correlation to the occurrence of landslide itself. Through the vegetational appearances especially on the upper part of landslide scar slope which is densely covered by trees, no recurrence of landslide was found. However, based on the historical report mentioned above, the succession of heavy rainfall actually occurred. Unfortunately, it is too difficult to analyze the trend of the presence of landsliding particularly in the baren site because the plant isn't informative.

In the case of landslide investigated in mudstone area, mixed stand which is mostly similar in age was used for the dating of landsliding. Landslide was estimated to have occurred in 1966 or several years before, about 20 years later than that landslide investigated in serpentine area. Thus, the development of landslide scar can clearly be seen. However, there were some difficulties in understanding precisely the frequency of landslide, and the process of mass movement. The magnitude of landslide is estimated to be about 5,500m^2 smaller than that landslide investigated in serpentine area. However, it is presumed that landslide has repeatedly occurred at the same slope site as the previous occurrence in which the deposited slope debris formed on the lowest part of landslide scar occupied about 380 m^2 in area, and partially blocked the stream. The newer landside, however, were relatively small (estimated approximately 1,100 m^2) with a sliding depth is about 2 meters. Those landslide activities were most likely related to the heavy rainfall recorded on April 8, 1962 in Horonobe district (HORONOBE TOWN OFFICE, 1974), located approximate 15 km of the west of the investigated area. Moreover that on October 25, 1970 the same destructive rainfall occurred again.

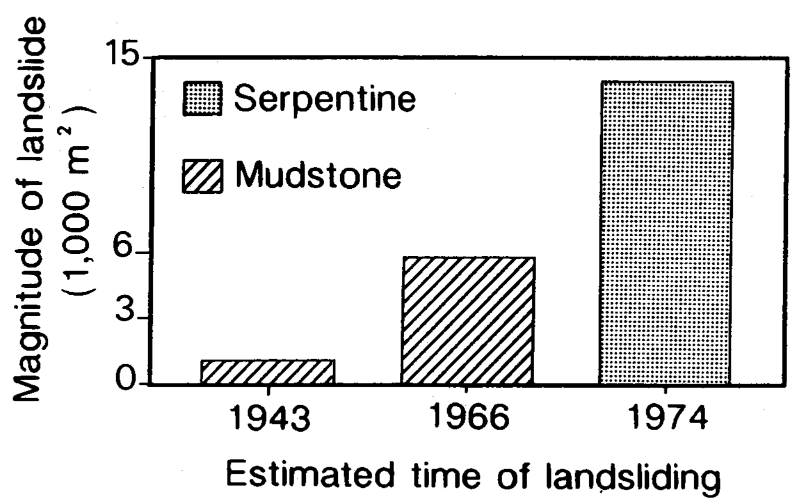

Fig. 14. Chronological landsliding in the investigated sites.

Figure 14 shows the characteristics of the magnitude and frequency of landslide in each investigated area. In the case of landslide investigated in serpentine area huge magnitude was found. However, no significant recurrence of landslide appeared within a long period of time (around 40 years). As for, in the landslide investigated in mudstone area, the magnitude was relatively small. However, it occurred more frequently than that in the serpentine area. At this point, it might be simply said that those characteristics may indicate the degree of stability of landslide site towards the major pursuing disturbance over a certain period of time. Those characteristics may also indicate the natural recovery rate of the landslide scar site particularly by natural revegetation.

VI. Conclusion

The slope surface forms in the investigated sites varied in accordance with its geological structure. The characteristics of soil seem to play a role in the transport process and in facilitating the form of slope surface as well. The fine grained, impermeable, and cohesive soils observable in the investigated sites of serpensine area are presumed to be the factors promoting the complex form of slope. Conversely, in mudstone area, the coarse, permeable, and unconsolidated surface soils are most likely the factors responsible for the extensive rectilinear form of slope. Great difficulties encountered in determining the process work on slope, which is imperceptible, and in tracing the changes of form and angle that slopes undergo with the passage of time explain for some unsolved questions. It is, therefore, advised that such investigation needs to be done many times, and carried out under a wider range of climatic, vegetational, and lithological condition before the true role of process in slope development can at least be assessed.

The movement of slope materials in both investigated sites was found to be different from each other. In the serpentine area, the slope materials mostly moved downward by small blocks of slide plane as indicated by crack and creep before moving. On the other hand, the slope materials in mudstone area mostly moved abruptly downward in a form of separate grain which has no indicator before moving. These tendencies were most likely related to their soil characteristics.

In the serpentine area, the type of mass movement was recognized to be as slump which occurred presumably 44 years ago. In the mudstone area, the type of mass movement was recognized to be as debris slide which occurred presumably 21 years ago, and was estimated to repeat 13 years ago.

The landslide scar in both the investigated sites were not fully covered by the invaded trees. Baren sites still remain widely on certain sites of the landslide scars. The distribution of invaded trees on vegetated sites was found to be different. In the serpentine area, the invaded trees mostly covered the upper part of slope in the form of a contour belt. This distribution is presumed to be related to the slope deformation after landsliding on which gentle sites were formed.

In the mudstone area, the invaded trees partially covered the landslide scar site of either on sloping sites or on the deposited slope debris site. This distribution in presumed to be related to the recurrence of landslide. Only these parts which were not stripped by the latest landsliding are still covered by vegetation.

The active soil movement in both the investigated landslide scars is regarded to be the

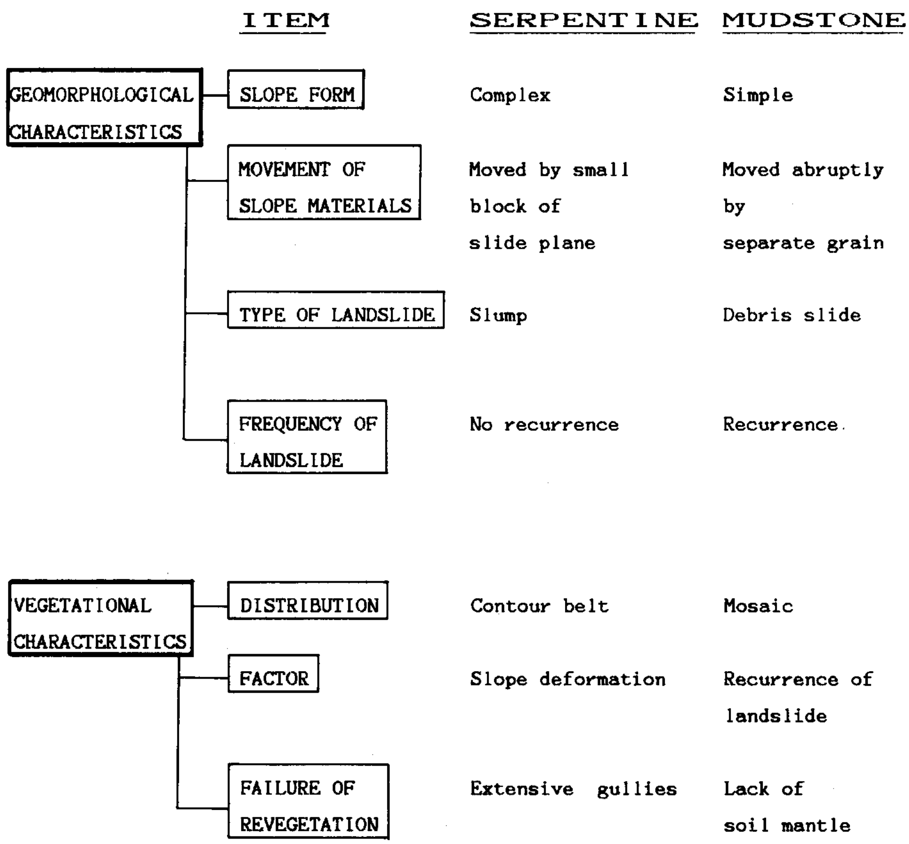

Fig. 15. Geomorphological and vegetational characteristics of the investigated landslide scars.

factor promoting the failure of natural revegetation. Moreover, the surface flows found in the downslope of landslide scar and the lack of soil mantle observable on the baren sites are also considered to be the limiting factors of the success of plant invasion.

Those geomorphological, and vegetational characteristics observed in both the investigated landslide scars is outlined in Fig. 15.

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要　約

山地流域における地すべり発生は，斜面において植生破壊，土地生産性の低下，さらに河川に対しても土砂の異常供給，濁水汚染，水生生物生息域の破壊など様々な悪影響を及ぼす。

本研究は，異なった地質条件下における地すべりの特徴とその跡地の斜面変動，植生回復過程を比較・検討することを目的とした。

問寒別川流域に存在する２ヶ所の地すべり跡地（以下，蛇紋岩地帯：S，泥岩地帯：M）において斜面形状，表層土質，表層土の移動状況，木本侵入状況（種・分布・齢）を調査し，比較・検討を行なった。

1．斜面縦断形状：Sは凸・凹・直線形から成る複合斜面（平均傾斜21°，斜面長200 m）であり，Mは直線形の崖錐斜面（傾斜38°，斜面長50 m）が続き，中央の脚部には崩土堆積地が認められた。

2．表層土移動：Sは蛇紋岩風化粘土から成っており，クラックが多く見られ，ブロック状

にクリープ移動（最大 60 cm/年）していた。M は泥岩風化礫（直径約 2 ～20 mm）から成っており，これらが風や雨滴の衝撃により落下，滑落していた。

3. 木本侵入：S, M ともに木本は部分的に侵入していた。S では斜面上部の緩傾斜部にカンバ類の同齢林（44 年生）が成立し，下部は裸地状で局部的に木本が侵入していた。M では崖錐部にカンバ類・ヤナギ類（21～19 年生）が侵入しており，崩土堆積地にはヤナギ類・ハンノキ類の同齢林（13 年生）が成立していた。

4. 地すべり発生：斜面形状，土質，木本侵入状況より，S は 44 年前に発生したスランプ（slump）型地すべりの跡地であり，M は 20 年前に発生した岩屑すべり（debris slide）型の地すべり跡地で，さらに 13 年前にその一部が再崩落したものと推察された。

5. 地すべり地の斜面変動：裸地部で生じている表層土移動形式の両地域における相異は地質条件の違い，すなわちクリープ移動は低排水性の蛇紋岩風化粘土（S），岩屑落下は低粘着性の泥岩風化礫に起因（M）しているものと考えられた。

6. 植生回復：植生回復が全面的に生じていないのは，表層土移動と土質によるものと考えられた。すなわち S では，クリープ移動・地表流発生による種子流失と過剰な滞留水による発芽への悪影響，M では表層土移動による種子流失が推側された。

7. 地すべり跡地の復旧に際しては，そこで生じている斜面変動状況，植生回復状況を把握することが重要であり，これらは地質条件によって異なるものと推測された。

Photo 1. Landslide scar investigated in the serpentine area.

Photo 2. Landslide scar investigated in the mudstone area.

Photo 3. Characteristics of slope materials in the serpentine area.

Photo 4. Characteristics of slope materials in the mudstone area.

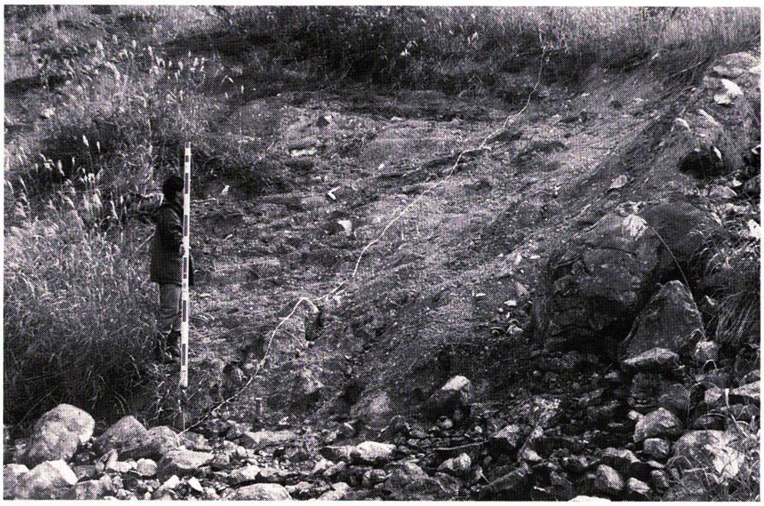

Photo 5. Soil creep measurement, carried out in the serpentine area.