Forest Recovery after Disturbance by the 1926 Mudflow at Mount Tokachi, Hokkaido, Japan

by

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十勝岳大正泥流による森林の攪乱と再生

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Abstract

Regenerated forests after the 1926 Mudflow on Mount Tokachi Volcano were studied with respect to species composition, tree age structure and their spatial distributions. Size distribution of sediment was also analyzed to determine the relationship between forest structure and disturbance intensity. Regenerated forests were not homogeneous in dominant species, height and age structures, displaying a mosaic distributional pattern in the riparian zone. Dominant species were *Picea glehnii*, *Picea jezoensis*, *Abies sachalinensis*, *Betula platyphylla* var. *japonica*, and *Betula ermanii*. They formed pure or mixed stands with other species. Tree height distribution of the stands could be classified into unimodal, platykurtic, bimodal, and reverse-J types. The establishment date of seedlings varied between stands. The earliest was three years after the mudflow. There was a close linkage between size distribution of sediment and forest type. *Betula* stands established themselves on sandy soil with dwarf bamboo on the forest floor, whereas *Picea glehnii* grew on gravelly substrata. The heterogeneous pattern in the spatial distribution of regenerated stands and their complex structures may be attributed to the difference in edaphic conditions reflecting disturbance intensity.

Key words : Disturbance ; Mudflow ; Recovery ; Size distribution of sediment
Nomenclature : Ohwi (1983)

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Introduction

A vast, bare area created by volcanic activity provides a good opportunity to study the process of primary succession (Yoshii 1932, 1942 ; Eggler 1959 ; Tagawa 1964). Causes of disturbances in volcanic areas include debris avalanches, lava flows, pyroclastic flows, mudflows, blast trees, and ash fall. These disturbances have various impacts on rates and directions of community recovery. Recovery processes are also dependent largely upon survival of original vegetation, residual propagule sources and edaphic conditions following disturbance. Lava flows, for example, are the most severe disturbance significantly impeding community recovery (Yoshioka 1942 ; Fosberg 1959), whereas blow-down and ash fall may leave surviving plants or propagule sources recovering rather quickly (Halpern *et al.* 1990 ; Tsuyuzaki 1989 ; Fujimoto *et al.* 1991).

Mudflow is mass-movement process characterized by a flowing mass of fine sediment mixed with large boulders with a high degree of fluidity. Mudflow can be classified as a volcanic disturbance of medium intensity, because it, in general, leaves a number of islands where vegetations and biological legacies are still alive and creates depositional hills suitable for vegetation recovery (Franklin *et al.* 1985). In 1926, the Furano River Basin experienced a large mudflow, the Taisho Mudflow, associated with the eruption of the Mount Tokachi Volcano, which is situated in latitude 43°25′ N and longitude 142°41′ E and is 2077 m above sea level. The mudflow destroyed approximately 600 ha of natural forest (Gotoh 1937). This mudflow was initiated at the summit of Mount Tokachi and developed into a huge mass movement as it moved downstream. It stretched about 2 km in width at an elevation of 900 m, and thereafter, it was diverted into many directions leaving a number of less disturbed islands.

There are no previous studies examining the entire spatial pattern of various stands with reference to their age distribution on Taisho Mudflow, although Hanaoka *et al.* (1982) investigated the classification of forest stands at an elevation of 700-1000 m, and Oikawa (1990) had monitored the successional process at small permanent plots. Further, most of the studies focusing on forest recovery processes after the volcanic disturbances had examined seed dispersal pattern and seedling establishment process within a few decades (Yoshioka 1942 ; Dale 1989 ; Halpern *et al.* 1990 ; Kimura 1991 ; Nakashizuka *et al.* 1993). A longer time span ranging from a few decades to a few centuries is required to understand the forest recovery process. The disturbance intensity should vary cross-sectionally and longitudinally on the mudflow. This creates spatial heterogeneity of geomorphic, edaphic site conditions, which influences the forest recovery processes.

The objective of this paper is to clarify the regeneration pattern on a high-magnitude mudflow on a basis of type classification of stands, their spatial distribution and recovery rate. First, we examined stand and age structures and species compositions of the forests in order to understand the regeneration pattern. Second, these stands types spreading 320 ha were mapped to observe their spatial pattern. Third, among the site conditions controlling forest recovery processes, we focus on size distribution of mudflow sediment because it reflects the tractive force of mudflow, and thereby disturbance intensity. This research was completed in 1992, 66 years after the eruption of Mount Tokachi Volcano.

Study Site and Methods

Study Site

The research site is located in the Furano River valley which originates from the Mount Tokachi Volcano (2077 m) and flows west (Fig. 1). At an elevation of about 600 m, the river slope varies from 11% (upstream) and 3% (downstream). The channel bed is V-shaped upstream of 900 m elevation and flows on gentle, wide slopes below this elevation. The river basin is thickly covered by volcanic tephra and toeslope slides are sporadically observed at sideslopes in the upstream reaches (Nakamura 1988). The study site is situated at an elevation of 530 m to 790 m where the original forests were destroyed by the mudflow.

The annual average temperature is 5.3°C and Warmth Index is 55.7°C • month at the Meteological Observatory of Biei Town (250m in elevation, 1979-1990) close to the field site, which means the study site is located at northernmost part of the Cool Temperate Zone. The annual average precipitation is 1310mm. The Warmth Index can be estimated as 40-45°C • month by taking decreasing rate of air temperature with elevation into account.

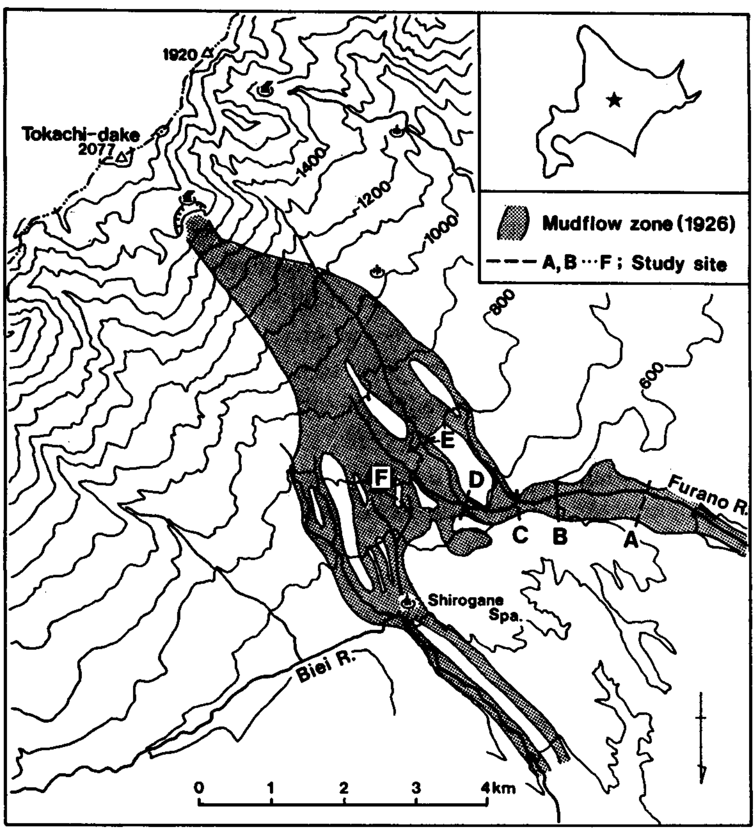

Fig. 1 The 1926 mudflow zone and study sites at Mount Tokachi Volcano.

The mean annual temperature is 2.2°C. Maximum and minimum mean monthly temperatures are 17.3°C (August) and −12.8°C (January), respectively.

Although vegetation at the study site before the 1926 eruption is not recorded in detail, Gotoh (1937) described the altitudinal distribution of tree stands briefly as follows: Areas between 500 m and 700 m were covered with young, broad-leaved stands regenerated after a forest fire prior to the 1926 eruption. These stands consisted of *Betula*, *Salix*, and *Alnus* spp., and *Phellodendron amurense* Rupr.. Conifers mixed with deciduous species such as *Betula* spp., *Sorbus commixta* Hedl., *Alnus japonica* Steud., and *Salix* spp. dominated at levels between 700 m and 1000 m. *Betula ermanii* dominated at elevations between 1000 and 1100 m, with conifers such as *Picea glehnii* Masters and *Abies sachalinensis* Masters. Above 1100 m in elevation, bare land with lava and gravel broadly extended, and mixed stands of *Pinus pumila* Regel and *Betula ermanii* were found sporadically.

Methods

We classified and mapped the regenerated forests on a basis of species composition and overstory height in a study area of 320ha, using aerial photographs. Large disaster prevention works were constructed on the Furano River since 1989, and forest stands on construction sites were removed. This provided a good opportunity to obtain accurate age information for the stands. Six cross-sectional lines corresponding to the dam sites were set up before dam construction began. Cross-sectional landforms were measured with levels and tapes. Thirty-eight stands were sampled, including five stands not damaged by the mudflow (Fig. 2). Areas of quadrats range from 25 to 400 m^2.

In stand analyses, height and diameter at breast height (DBH) were measured for trees taller than 1.3 m, except for C3 and C5 plots where trees taller than 0.3 m were measured. Cross-sectional disks were collected near the base of trees (10 to 55 cm above the ground) for age determination. Samples were selected to represent a range of tree height of prevalent species in each quadrat. For about half of the sampled trees, additional sample disks were taken at ground level to estimate the initial growth rate of trees. Finally, tree ages were adjusted by adding years calculated from their initial growth rate. Species and coverage of understory vegetation were recorded to determine the understory type.

Size distribution of sediment was measured at seven sites corresponding to stand types. Unfortunately, sediment samples were not collected in the same quadrats as the forest stands under investigation, because dam construction was completed before our sediment sampling. However, these sample units were installed in the homogeneous forest patches along the B and D lines where forest structures were investigated (Figs. 2, 3 and 4). Visual inspection indicated that substrate composition does not vary within a patch but varies significantly between patches. We set up sample units along the two lines to examine cross-sectional and longitudinal variations in sediment deposits with special reference to stand type. Sediment was collected 1 m^2 in area and 0.2 m in depth. Particles larger than 5.0 cm were selected and three axes of particles size were measured in the field. Other particles smaller than 5.0 cm were taken to the laboratory, oven-dried to measure water content, and sieved for 15 minutes in a mechanical shaker for particles larger than 0.074mm. The particle size distribution was expressed by cumulative curve.

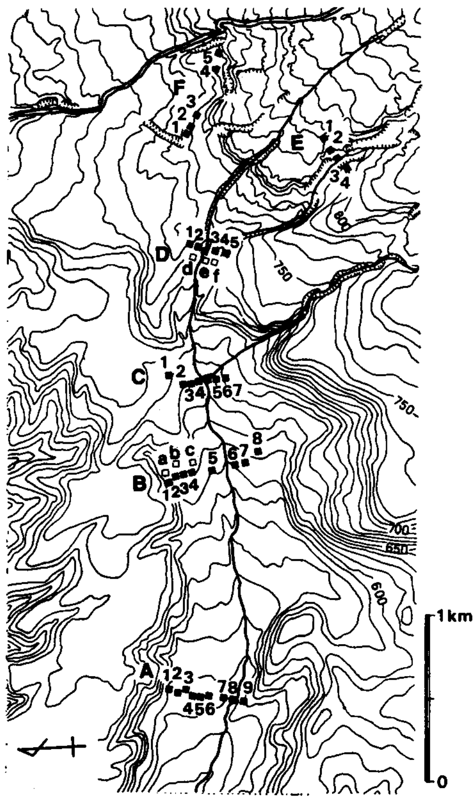

Fig. 2 Location of cross-sectional lines, forest stands (denoted by black squares) and soil samples (denoted by white squares) investigated.

Results

The general characteristics of 38 sample stands, including five stands undisturbed by the 1926 mudflow, are listed in Table 1. The undisturbed stands were well-developed, mixed stands, predominantly consisting of *Picea jezoensis* Carr., *Abies sachalinensis*, *Picea glehnii* and *Betula platyphylla* Sukatchev var. *japonica* Hara. The dominant height and basal area (BA) of these stands ranged from 18.0 to 25.3 m and from 29.08 to 72.59 m^2/ha, respectively.

The 33 stands disturbed by the mudflow showed a wide variation in dominant species, dominant height and BA (Table 1). The number of stands dominated by *P. glehnii*, *B. platyphylla* and *B. ermanii* were 11, 8 and 6, respectively. Although neither *P. jezoensis* nor *A. sachalinensis* showed a high BA-value alone, the two species tended to be mixed. Therefore, we refer to this stand type as two-species dominant. Six stands belong to this type. Two other stands dominated by *Phellodendron amurense* and *Alnus japonica* were observed in the study site. As a result, the 33 stands were classified into 6 stand types. Besides dominant species, twelve tree species, such as *Sorbus commixta*, *Alnus hirsuta*, *Salix hultenii* var. *angustifolia* Kimura, *Acer japonicum* Thunb., and *Acer ukurunduense* Trautv. et Mey., and so forth, were present in small numbers.

Although birch stands appeared in all cross-sectional lines (A-F), other broadleaved species, such as *P. amurense* and *A. japonica*, appeared only in the A line located at the lowest elevation. Stands dominated by *B. platyphylla* were found in the A, B and C lines located below 700 m in elevation, and their dominant heights ranged from 13.3 to 26.0 m. *B. ermanii* stands occurred in the D, E and F lines located above 700 m. Their dominant heights ranged from 11.2 to 15.5 m, which was shorter than that of *B. platyphylla* stands. Stands dominated by *P. jezoensis* and *A. sachalinensis* occurred only in the A, B and C lines, and had a wide range of dominant height (7.0 to 19.6 m). *P. glehnii* stands appeared on all lines, and their dominant heights were low, ranging from 4.2 to 17.5 m. Especially, dominant heights less than 10 m were observed in the high elevation lines (C, D, E and F). The variety of forest types in a cross-sectional line increased with decreasing elevation.

Table 1 General description of sample plots

Plot	Elevation (m)	Dominant height (m)	Basal area (m^2/ha)	Dominant species (BA, %)		Understory type	Range of age (years, No. of samples)	
A1	537	20.8	30.81	Pa	(84)	Sasa	67— 71	(9)
A2	538	13.0	24.98	Aj	(84)	Reed	18— 52	(9)
A3[r]	538	6.1	7.14	Pg	(93)	Reed, Sasa	37— 53	(12)
A4[b]	538	17.5	34.40	Pg	(56)	Reed, Sasa	25—222	(6)
A5	538	13.4	28.05	Pg	(54)	Moss	48— 56	(9)
A6	536	26.0	18.30	Bp	(100)	Sasa	31— 51	(8)
A7	532	14.5	39.64	Pj, As	(40)	Moss**	39— 56	(11)
A8	532	9.2	11.09	Pj, As	(67)	Moss, Reed	15— 40	(7)
A9*	542	24.0	49.43	Bp	(31)	Sasa	—	
B1	604	19.4	28.06	Bp	(97)	Sasa	53— 60	(6)
B2	605	10.5	62.56	Pg	(98)	Shrub**	46— 52	(12)
B3[b]	606	14.1	46.17	Bp	(64)	Sasa	41— 58	(19)
B4[b]	608	17.2	37.49	Bp	(73)	Sasa	42— 54	(10)
B5[r]	604	7.0	16.05	Pj, As	(62)	Shrub**	42— 50	(9)
B6[b]	606	19.6	61.43	Pj, As	(81)	Shrub**	41— 56	(30)
B7[b]	606	19.5	39.52	Bp	(53)	Sasa	43— 58	(21)
B8*	614	22.0	57.33	Pj, As	(66)	Sasa	—	
C1	653	18.7	30.33	Bp	(94)	Sasa	28— 59	(11)
C2[r]	640	13.3	39.66	Bp	(46)	Moss**	39— 52	(15)
C3[r]	642	4.2	0.97	Pg	(81)	Moss**	27— 50	(7)
C4[r]	642	10.1	31.51	Pj, As	(53)	Moss**	31— 54	(14)
C5[r]	642	7.9	20.37	Pg	(48)	Moss**	34— 52	(16)
C6[p]	646	19.0	45.76	Pj, As	(64)	Sasa	38— 57	(16)
C7[p]	649	20.8	28.83	Bp	(62)	Sasa	54— 60	(8)
D1*	724	20.9	50.24	As	(48)	Sasa	—	
D2[p]	716	13.1	19.08	Be	(76)	Sasa	37— 54	(8)
D3[r]	709	7.8	23.37	Pg	(70)	Shrub**	28— 52	(18)
D4[b]	708	11.4	45.81	Be	(56)	Shrub**	37— 56	(14)
D5*	717	18.0	29.08	As	(49)	Sasa	—	
E1[b]	788	12.6	39.56	Be	(92)	Sasa**	47— 58	(9)
E2[r]	778	5.4	7.31	Pg	(71)	Shrub**	34— 55	(11)
E3[r]	778	6.7	13.04	Pg	(66)	Shrub**	40— 55	(9)
E4	783	11.2	31.37	Be	(55)	Sasa	44— 60	(6)
F1[r]	728	8.4	34.09	Pg	(84)	Shrub**	11— 50	(20)
F2[b]	731	15.5	30.44	Be	(73)	Sasa**	43— 61	(14)
F3*	744	25.3	72.59	Pj	(51)	Sasa	—	
F4[b]	759	12.9	22.44	Be	(70)	Sasa**	41— 63	(17)
F5[r]	760	4.9	6.17	Pg	(94)	Shrub**	27— 57	(16)

[b]: bimodal height distribution, [p]: platykurtic height distribution, [r]: reverse-J shaped height distribution, *: undisturbed stand, **: boulder-rich site, —: not measured. Height distribution of a stand without any alphabetic superscripts is unimodal. Dominant height is the mean height of the taller 10% of trees. Species abbreviations; Pg: *Picea glehnii*, Pj: *Picea jezoensis*, As: *Abies sachalinensis*, Bp: *Betula platyphylla* var. *japonica*, Be: *Betula ermanii*, Pa: *Phellodendron amurense*, Aj: *Alnus japonica*. Sasa includes *Sasa senanensis* and/or *Sasa kurilensis*.

Cross-sections of landforms and diagrammatic profiles of forest stands at lines A, B and D are given in Fig. 3. Downstream cross-sections A and B show the land surfaces with undulating micro-relief, whereas upstream cross-section D shows an incised and constrained valley shape. *P. glehnii* stands tended to be distributed near the present stream channel or on the low ground surface in a cross-section. Broadleaved trees, such as *Betula* spp., were found at the margin of the mudflow or on the high ground surface in a cross-section. Stand types were alternated within a short distance (about 20 to 50m).

The spatial distribution of each stand type classified solely by dominant tree species is shown in Fig. 4. Forests dominated by broad-leaved trees were distributed over the northern margins, while coniferous and mixed stands dominated near the stream and along southern margins, with scattered patches of bare land. These forests create a mosaic pattern of elongated patches parallel to the stream. Coniferous, broadleaved and mixed stands accounted for 78.6 (24.3%), 94.9 (29.3%) and 77.5ha (23.9%) out of the total area of 323.8ha, respectively. They also extended about 25-250 m in width. Bare land, not including the stream site, was 28.9 ha, and regenerated forests covered 90 % of the disturbed site by the mudflow in area.

Forest floor vegetation was classified into four types, such as sasa (dwarf bamboo)-, shrub-, moss- and reed-type (Table 1). Forest floor vegetation was closely related to dominant tree species. Typical combination were *B. platyphylla* with sasa-type and *P. glehnii* with shrub- or moss-type forest floor vegetation. *B. ermanii* was coupled with sasa- or shrub-type. Most conifer stands consisting of *P. jezoensis* and *A. sachalinensis* were also associated with shrub-type.

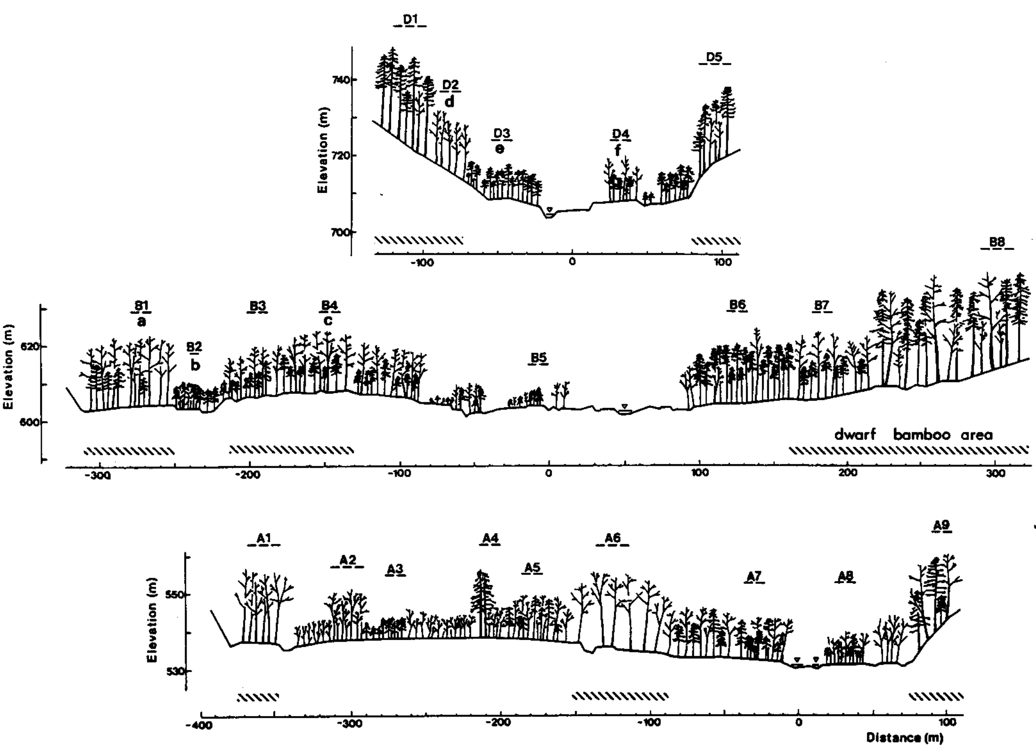

Fig. 3 Cross-sectional views of landforms and forest stands in the lines A, B and D with location of investigated sites(Fig. 2). These diagrams were drawn by looking upstream at the cross-sections.

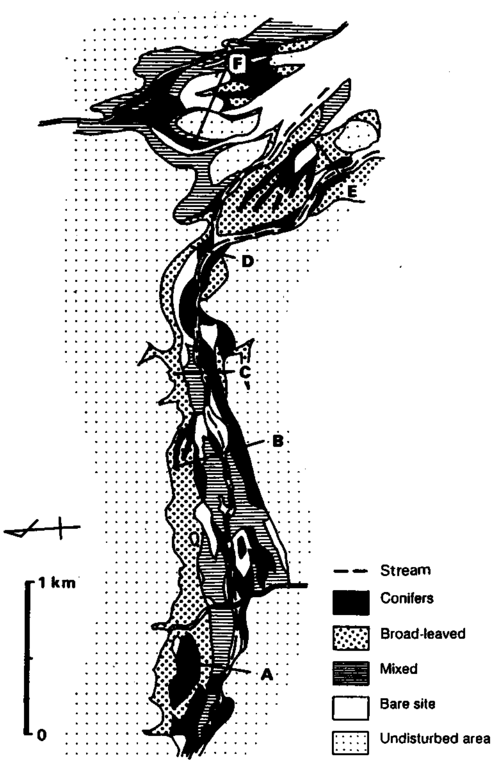

Fig. 4 Regenerated forest stands interpreted by aerial photographs. Elongated patches of classified stands were distributed parallel to the mudflow direction.

The maximum ages of most stands ranged from 40 to 63 years old, indicating that they were established in 3 to 26 years after the mudflow, except for A1 and A4 (Table 1). The height distributions in most stands dominated by birches were either unimodal or bimodal. The bimodal distributions were caused by the combination of canopy birch trees and understoried conifers. The maximum ages of *B. platyphylla* stands ranged from 51 to 60 years old. Although age range of *B. platyphylla* trees in each stand differed widely from 3 (B7) to 31 years (C1), canopy birch trees exhibited more narrow ranges, in many stands less than 10 years (for example, age of canopy birches ranged from 49 to 59 in C1). Understoried conifers showed approximately equivalent maximum age to overstoried birch trees.

Most *B. ermanii* stands exhibited the maximum ages of canopy birch trees from 54 to 63 years old, and their age range was from 11 (E1) to 22 (F4) years. The maximum ages of conifers in the understory of stratified stands were equal to or less than that of *B. ermanii*. The height distribution of many conifer stands were reverse-J shaped. The maximum ages (50–57 years old) of these stands indicate that they were initiated 9–16 years after the mudflow. The maximum age of each conifer species in a stand was almost similar to each other, even if a stratification occurred between species. The variation of height growth of conifers in a stand was larger in comparison with birches, and individual establishments of conifers were less concentrated than those of canopy trees of birches.

Size distribution of sediment is shown in Fig. 5 for 6 samples. Particle size distribution differed significantly among samples (Kruskal-Wallis test, $p<0.001$), and can be classified posteriorly into two groups. The first group consists of the *a, c, d* and *f* plots where fine particles (less than 0.085 cm in diameter) accounted for more than about 60% of the total weight. These plots were dominated by birches (Fig. 2, 3 and Table 1). Water contents of these plots were relatively high, ranging from 25 to 56% in weight percentage, and aggregated soil structure was prominent. Sediment distributions in the c and f were somewhat different from those in the *a* and *d*, especially in showing an increase in 3.75–10 cm particle sizes (Fig. 5). Height distributions of the *c* and *f* were also different from the *a* and *d*, and those in the former were bimodal structures constructed by birch and conifers and in the latter unimodal ones (Table 1).

Plots *b* and *e* make up the second group, where the proportion of the fine particles is much lower comparing with the first group. Coarse particles larger than 5.3 cm accounted for about 70% of the sediment in this group. Water content was 15 and 21% in each plot. These plots were located in the *P. glehnii* patches (Fig. 2, 3 and Table 1).

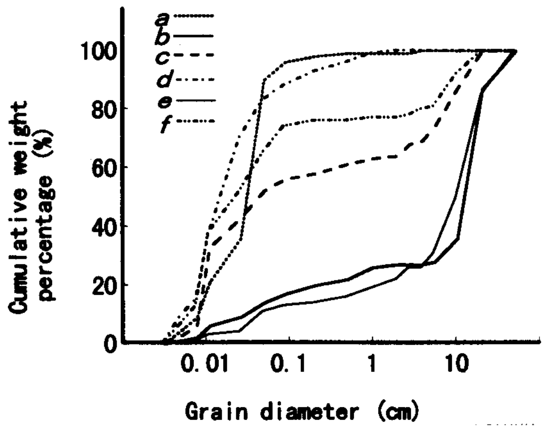

Fig. 5 Particle size distribution of soil samples expressed by cumulative weight curves.

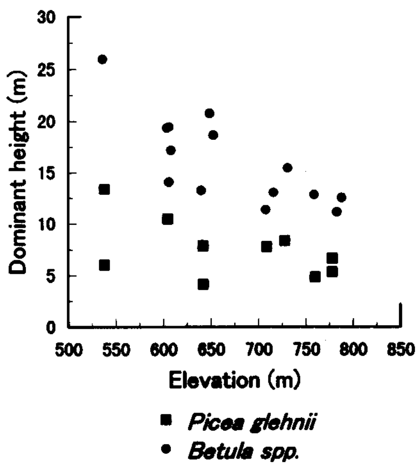

Fig. 6 Relationships between elevation and dominant height of *Betula* spp. and *Picea glehnii* stands. Only a correlation coefficient for *Betula* spp. stands is significant ($p < 0.01$).

Discussion

The structure of regenerated forests following a large-scale geomorphic disturbance varies with the type of disturbance, its intensity, distance from available seed sources and residual propagule sources (Franklin *et al.* 1985, Tsuyuzaki 1987, Halpern *et al.* 1990). The forest regenerated after the mudflow on Mt. Tokachi exhibited a quite heterogeneous structure, constituting of a mosaic of various elongated patches that differed in dominant species, size and age structures. Most pre-disturbance forests were considered to be completely devastated. The stand A1, showed the maximum age more than 66 years old, may have regenerated from vegetative propagule sources because they established just before or after the mudflow. The stand A4, which has trees more than 220 years old in its overstory, was created where the mudflow killed only undergrowth. This stand is located on the highest ground in the valley floor cross-section (Fig. 3). However, the above cases were exceptions. Dominant species found in the mudflow area are all wind-dispersed, and probably they were regenerated from seedlings. Nakashizuka et al. (1993) reported a vegetation development course after a debris avalanche which destroyed a forested area to a degree similar to the Taisho Mudflow. They recognized three processes of vegetation recovery: survival of plants through the disturbance, survival of seed buried in the pre-disturbance soil, and dispersal after disturbance. They concluded that wind dispersal plays an important role in the early revegetation processes. Our results at Mt. Tokachi support this conclusion.

The initiation of seedling establishment varies from 3 to 26 years after the mudflow. Gotoh (1937) reported the establishment of *Betula* spp. seedlings 3 to 5 years after the mudflow. *Alnus maximowiczii* Callier seedlings on Mt. Higashi-Tengu, central Japan, began to invade 4 to 6 years after the mudflow, followed by *B. ermanii* (Kimura 1991). Seedlings were established on Mount Bandai, northeastern Japan, 6 to 7 years after a mudflow (Hiroki 1979). The results of the present study indicate various dates of seedling establishment, although the earliest date was similar to the results of above previous studies. In our study, it is difficult to attribute a 3-5 year delay of seedling establishment to poor seed crops and distance from seed sources, because sufficient seed crops of conifers were observed in the same year as the mudflow and 2 years after the mudflow in undisturbed forest along the margins of the mudflow (Gotoh 1937). The differences in seedling establishment dates on various patches of the mudflow surface is considered to be affected by the heterogeneity of disturbance intensity and stability of the ground surface and by distance from seed sources (Yoshioka 1966).

There was an obvious correlation between the size distribution of sediment and the dominant tree species (Fig. 4). We assumed that sediment has been preserved to some extent since beginning of vegetation recovery, because aerial photographs, landforms and growing trees did not show any signs of a large, secondary mass movement. Size distribution of sediment reflects water holding capacity and rate of aeration, that directly influence seedling establishment and growth (Hupp and Osterkamp 1985; Ishikawa 1988; Aruga *et al.* 1996).

Betula stands favor sandy sediment and were distributed over the margins of the mudflow where transported fine sediment could be deposited due to the low velocity of the mudflow. Dwarf bamboo (sasa) dominated the understory of *Betula* stands (Fig. 3). Since *Betula* spp. grow quickly and bamboo covered densely the forest floor, other tree species were inhibited, resulting in a pure and even-aged *Betula* stand. Distributions of dwarf bamboo and sandy sediment overlapped closely because the rhizome of dwarf bamboo easily penetrates into sandy sediment, as opposed to stony sediment which impedes rhizome extension.

Picea glehnii seedlings established on cobbly sediment, and were distributed over the central areas of the mudflow where the surface soil was intensively scoured by the high energy of the mudflow. This correspondence between *P. glehnii* and coarse fragments of sediment was also found on Mt. Hayachine, where *P. glehnii* established on stony substrata created by debris flow deposits (Matsuda *et al.* 1978). There are few studies discussing forest regeneration with special reference to sediment texture, except for those studies focusing on the distribution of *Salix* spp. (Niiyama 1987, 1989) and on the distribution of various tree species in riparian zones (Johnson *et al.* 1976). Kimura (1991) examined the relationship between soil and forest recovery and found that differences in soil texture contributed to the establishment of *Alnus maximowiczii* and *B. ermanii*.

Age census of *Betula* stands showed that the vertical structure was determined by both seedling establishment pattern and their growth rates. Stratification between *Betula* spp. and associated conifers is attributable to the difference in growth rates when they invaded simultaneously, or to the late establishment of conifer seedlings. The stands showing a reverse-J shape in height distribution may be due to both a difference in growth rates and the asynchronous establishment of seedlings. These stands have not grown as much as other *Betula* stands, and showed a wide variation in establishment dates. Interestingly, coniferous seedlings were able to invade prior to *Betula* spp. in some stands established in areas close to the stream channel or on other areas of low ground in cross-sections. Both habitats are underlaid by stony, sandy sediment. Coarse fragments of mudflow sediment may provide a habitat for coniferous seedlings.

Dominant height of *Betula* and *Picea* trees vary along the altitudinal gradient (Table 1, Fig. 6). In lower elevations, the mudflow resulted in light damage and formed thin deposits on the wide, gentle valley floor (Araya *et al.* 1991). These thinner deposits permits quicker access to more nutrient rich pre-mudflow soils. On the other hand, in the upstream section where the valley is steep and constrained by narrow valley walls, the mudflow severely eroded the ground and created exposed, hard mineral soil conditions. The maximum ages of these stands are similar, and there are no differences in dominant height of the undamaged stands along the altitudinal gradient. Therefore, the altitudinal variation in heights of these two species can be attributed to the difference in deposit thickness and erosion intensity.

In the present study area, the mudflow created heterogeneous habitats, characterized by a micro-relief, wet and dry conditions, and sandy and cobbly substrata (Figs. 3 and 4). The extent of soil removal by mass movement greatly affects vegetation recovery after geomorphic disturbances (Langenheim 1956). A small, low-magnitude disturbance leaving surface soil allows rapid recovery (Kimura 1991), whereas a large, high-magnitude event creates boulder-rich and nutrient-poor substrata, resulting in delayed vegetation recovery (Nakashizuka *et al.* 1993). Therefore, the recovery process after a mass movement is determined by its size and intensity (del Moral & Wood 1988). We conclude that heterogeneity in disturbance intensity and site stability significantly influenced forest recovery on the Taisho Mudflow and created a mosaic of forest patches oriented parallel to the stream direction.

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要　約

1926年の十勝岳大正泥流跡地に再生した森林について，林分構造と齢構造およびそれらの空間配置を解析した。また，再生林の構造と攪乱の強度との関係を検討するために，地表堆積物の粒径組成を調査した。再生林は，優占種，林分高および齢構造からみて不均質であり，構造の異なる林分が泥流流下跡地にモザイク状に配列していた。優占種はアカエゾマツ（*Picea glehnii*），エゾマツ（*Picea jezoensis*），トドマツ（*Abies sachalinensis*），シラカンバ（*Betula platyphylla* var. *japonica*），ダケカンバ（*Betula ermanii*）であり，再生林はそれらの純林または混交林分の集合であった。調査林分の樹高分布には一山型，緩尖型，二山型，逆J型がみられ，林分高もさまざまであった。樹木の定着時期は林分によって異なっており，もっとも早い林分は泥流の3年後からであった。林分のタイプと地表堆積物の粒径組成との間には密接な関係が認められた。カンバ優占林分は細粒の砂質土に成立していた。アカエゾマツは礫の多い堆積物上に優占していた。再生林分の多様な林分構造とその不均質な空間配置は，泥流による攪乱の強度に起因する土性の変異を反映したものと考えられた。